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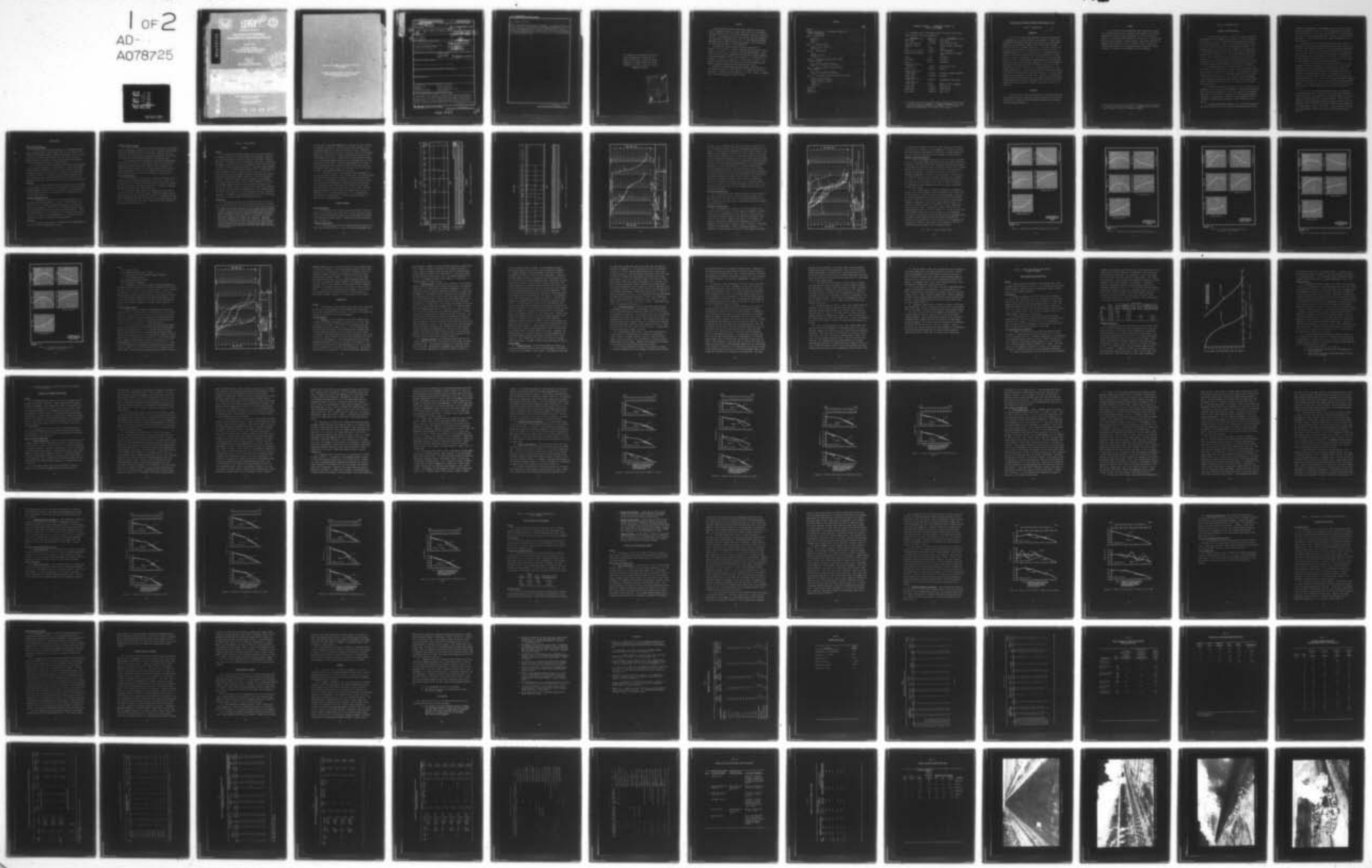

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TECHNICAL REPORT GL-79-21

# UTILIZATION OF MARGINAL CONSTRUCTION MATERIALS FOR LOC

by

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November 1979
Final Report





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Under Project No. 4A762719AT40
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**20. ABSTRACT (Continue on reverse side if necessary and identify by block number):**


The purpose of this report is to develop methodology and procedures for using marginal quality aggregates (aggregates not meeting existing specifications) in the construction of asphalt and portland cement concrete surface pavement layers. The report describes a laboratory study performed on bituminous mixes made from marginal aggregate materials and the testing of a specially designed test section consisting of both flexible and rigid pavement

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20. ABSTRACT (Continued)

surface layers made of marginal quality aggregates. Also presented are construction techniques and the behavior of the marginal aggregate mixes subjected to accelerated 5-ton military dump truck and two types of tracked vehicle traffic. Recommended properties of asphalt and portland cement concrete mixes made of marginal aggregate materials are presented to aid the military engineer in constructing paved surfaces that are to be used only for limited traffic and short periods of service life.

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# PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers (OCE), U. S. Army, under Project No. 4A762719AT40, Task A2, Work Unit 017, "Utilization of Marginal Construction Materials for LOC." The responsibility for conducting the study was assigned to the Geotechnical Laboratory (GL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The investigation was conducted from July 1975 to September 1978.

The study was conducted under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively, of GL, and R. L. Hutchinson, Pavement Program Manager. Engineers of the GL actively engaged with the planning, testing, analyzing, and reporting phases of this study were Messrs. R. L. Hutchinson, A. H. Joseph, C. D. Burns, T. D. White, E. R. Brown, and R. W. Grau. This report was written by Mr. Grau except for the portion regarding bituminous laboratory testing, which was written by Mr. Brown.

Directors of the WES during the investigation and preparation of this report were COL G. H. Hilt, CE, COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown. Messrs. D. Barnard and L. Price were technical monitors for OCE.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| cubic yards | 0.7645549 | cubic metres |
| cubic yards per hour | 0.7645549 | cubic metres per hour |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |
| feet | 0.3048 | metres |
| gallons (U. S. liquid) | 3.785412 | cubic decimetres |
| gallons per square yard | 4.5273 | cubic decimetres per square metre |
| inches | 2.54 | centimetres |
| kips (mass) | 453.5924 | kilograms |
| microns | 0.001 | millimetres |
| miles per hour (U. S. statute) | 1.609344 | kilometres per hour |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square inch | 0.6894757 | newtons per square centimetre |
| pounds (mass) | 0.45359237 | kilograms |
| pounds (mass) per cubic foot | 16.01849 | kilograms per cubic metre |
| pounds (mass) per cubic inch | 27.6799 | grams per cubic centimetre |
| square feet | 0.092903 | square metres |
| square yards | 0.8361273 | square metres |
| tons (mass) | 0.90718474 | metric tons |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

## UTILIZATION OF MARGINAL CONSTRUCTION MATERIALS FOR LOC

## PART I: INTRODUCTION

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### Background

1. The cost of constructing pavements is continually rising due to increasing cost of labor, materials, and equipment. Current Corps of Engineers (CE) design procedures allow only the use of high-quality aggregates for base courses, asphalt, and portland cement concrete mixtures to be used in pavement facilities. In a recent related study, procedures were developed for upgrading native in-place soils and aggregate materials for use in the construction of subgrades and base courses for airfields, roads, heliports, and storage areas in forward areas of a theater of operations (TO). The results of this study were reported in the U. S. Army Engineer Waterways Experiment Station (WES) Instruction Report S-74-3 entitled "Stabilization of Soil and Aggregate Materials for Forward Area Operations," dated September 1974.[1] The study reported herein involves the use of marginal materials for the surface pavement layer. Many military operations require paved surfaces for roads, airfields, heliports, parking aprons, etc., for only limited traffic and short periods of service life. Therefore, if satisfactory flexible and rigid pavement mixtures for limited operations can be made using marginal native materials (aggregates that do not meet existing specifications), considerable savings in construction cost can be realized.

### Objective

2. The objective of this investigation was to develop methodology and procedures for use of materials exhibiting properties that exclude them from use in asphalt and portland cement pavements under existing criteria and specifications.

## Scope

3. The objective of this investigation was accomplished by means of a laboratory study and the construction and testing of two specially designed test sections as described herein. The test sections were subjected to accelerated traffic using various loads on a 5-ton* military dump truck and two types of tracked vehicles. This report describes the materials used in the test sections, laboratory study, construction techniques, and behavior of the marginal material mixes under traffic. A summary of findings and recommendations is also presented.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

## PART II: LABORATORY TESTS

### Asphalt Concrete Mixtures

4. In design and construction of conventional mixes, experience has shown that good performance can be expected if certain procedures are followed. First, it is necessary that the aggregate and asphalt are of acceptable quality. Test results obtained from various tests are used to evaluate the quality of the aggregate and asphalt. For aggregate quality, these tests include: gradation, Los Angeles abrasion, fractured faces, flat and elongated count, sulfate soundness, specific gravity, absorption, etc. For asphalt quality, these tests include: specific gravity, viscosity, penetration, ductility, thin film oven test, etc. Past experience has shown that when the abovementioned tests are within the desired range, an acceptable mix can be prepared by mixing the proper amount of asphalt with the aggregate.

5. For high-quality asphalt concrete mixtures, the CE uses the Marshall mix design procedure to determine the optimum asphalt content and to evaluate the properties of the mix. Mix properties, such as unit weight, voids total mix, voids filled with asphalt, stability, immersion compression test, and flow, are evaluated. When the aggregate, asphalt, and asphalt-aggregate mixture meet the specified requirements, the mix, properly placed in the field, is expected to provide satisfactory performance.

6. In many cases, especially in the TO, it may be necessary to use aggregates that do not meet the requirements for high-quality pavements. Hence, design and construction criteria are needed for these marginal materials. It is desirable to develop criteria whereby any aggregate, regardless of quality, can be mixed with a given asphalt and the mix quality can be determined on the basis of tests conducted on this mixture.

7. A laboratory testing program was set up to evaluate mixes prepared from combinations of two uncrushed coarse aggregates and three

uncrushed fine aggregates. These aggregates did not meet the requirements for gradation or plasticity. The five aggregates used included: (a) clayey sand (SC), S1; (b) concrete sand (SP), S2; (c) masonry sand (SP), S3; (d) gravelly-clayey sand (SC), G1; and (e) nonplastic gravelly sand (SP), G2. The test properties describing these aggregates are shown in Table 1.

8. The tests used to evaluate the mixture prepared with these aggregates included the conventional Marshall tests (unit weight, voids, total mix, voids filled with asphalt, stability, immersion compression, and flow). The indirect tensile test and the direct shear test were also conducted. Other tests that required sophisticated equipment or test procedures were not considered for this study. Since this study included pavement construction in the TO, it was felt that only simple testing equipment and procedures would be applicable.

9. Asphaltic concrete mixes were prepared with each of the five aggregates. Different combinations consisting of one of the coarse aggregates and one of the sands were also mixed with asphalt and evaluated. The conventional Marshall mix design method was used to determine the optimum asphalt content for each aggregate blend. The criteria for sand mixes designed for low-pressure tires were used to design the sand mixes. The criteria for dense-graded aggregate designed for low-pressure tires were used to design the mixes containing coarse aggregate.[1] The asphalt binder used for these laboratory tests was an 85-100 penetration grade asphalt with test properties as shown in Table 2.

10. A total of 36 different aggregate blends were prepared and tested during this study. Thirty-four of the blends were composed of marginal materials; for comparison, one blend was composed of crushed gravel, and one was composed of crushed limestone. A mix design to determine the optimum asphalt content was conducted on each of the 36 aggregate blends. Additional tests were conducted on mixes prepared at optimum asphalt content. The results of these additional tests and the optimum asphalt contents for each of the 36 mixes are shown in Table 3.

## Test Results

Voids total mix and
voids filled with asphalt

11. The voids in the total mix measured in the marginal material mixes at optimum asphalt content ranged from 3.6 to 7.2 percent. The criteria for bituminous surface course and sand asphalt are 3-5 percent voids and 5-7 percent voids, respectively. The voids filled with asphalt criteria for bituminous surface courses and for sand asphalts are 75-85 percent and 65-75 percent, respectively.

12. For some of the mixes, especially those with a high percentage of voids in mineral aggregate, it was difficult to select the optimum asphalt content so that both the voids total mix and the voids filled with asphalt would meet the criteria. For example, it was impossible to select for sand No. S1 an asphalt content in which both the voids total mix and the voids filled with asphalt met the criteria. For a case such as this, the voids total mix criteria were used as the control.

Stability

13. For the 50-blow Marshall design procedure, which is currently used for paving mixtures subjected to tire pressures of 100 psi or less, a minimum Marshall stability of 500 is required. For the mixes made with the marginal materials, the stability values ranged from 112 to 1410 as shown in Table 3.

Immersion compression test

14. Approximately 40 percent of the mixes evaluated met the retained stability requirement of 75 percent. However, most of the mixes that met the retained stability requirements did not meet the stability requirements. Only five of the 35 marginal material mixes met the requirement for both stability and retained stability. These five mixes included: (a) 100 percent S1, (b) 25 percent G1 and 75 percent S1, (c) 80 percent G2 and 20 percent S1, (d) 50 percent G2 and 50 percent S1, and (e) 20 percent G2 and 75 percent S1.

Flow test

15. As shown in Table 3, all of the mixes met the requirements for flow at 20 or less optimum asphalt content.

Indirect tensile strength

16. The indirect tensile test is a new test, which is not normally used for evaluating an asphaltic concrete mix. However, since the materials to be used had had very little testing, it was felt that the indirect tensile test should be conducted to determine if the strength of the mix could be better evaluated than by conventional tests.

17. The indirect tensile strength for the marginal material mixes varied from 17 to 108 psi. It was observed that there is a general relationship between stability and indirect tensile strength. All samples that had an indirect tensile strength greater than 45 psi had a stability greater than 500 lb. All samples that had an indirect tensile strength less than 45 psi had a stability less than 500 lb.

Direct shear strength

18. Like the indirect tensile test, the direct shear test is not normally used for evaluating an asphaltic concrete mix. Again, since the materials to be evaluated had not been used in the past, it was felt that the direct shear test might show ability to evaluate the marginal materials better than other conventional tests.

19. The direct shear strength of the marginal materials varied from 72.8 to 202 psi. These test results indicated a general relationship between direct shear strength and stability. All samples that had a shear strength greater than 130 psi had a stability value greater than 500 lb. All samples that had a shear strength less than 130 psi had a stability value less than 500 lb.

## PART III: TEST SECTIONS

### Design

#### General

20. The rigid and flexible pavement test sections were designed to determine the effects of traffic during various weather conditions on the portland cement concrete and bituminous mixes made of marginal materials. Therefore, both test sections were constructed of sufficient thicknesses to prevent base course or subgrade failures during the traffic period. Thickness design procedures for rigid and flexible pavement roads were used to determine these thicknesses.*[3,4] A tandem-axled M-51 cargo truck was selected to traffic these test sections. Both test sections contained a mix designed according to specifications and were trafficked along with the marginal material mix items for comparative purposes. The portland cement concrete standard mix was designed according to American Concrete Institute (ACI) Standard 211.3-75,[5] and the standard bituminous concrete mix was designed according to TM 5-822-8.[2] The primary variables in the flexible pavement test items were the asphalt content and types of aggregates used in the marginal material mixes. The variables in the rigid pavement were type of material and method of placement. These aggregate materials are described under the section on Pavement Elements (see paragraphs 23-31).

#### Description

21. The marginal material test sections were laid out to tie in with an existing perimeter road along the western boundary of the WES.

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* It should be noted that although the rigid pavement design procedure is based on the critical tensile stresses produced within the slab by a vehicle loading[2] and that the flexible pavement design procedure is based on equivalent 18,000-lb, single-axle, dual-wheel load operations,[3] the traffic levels referred to in this report for the rigid and flexible pavement test sections are converted to equivalent 18,000-lb, single-axle, dual-wheel load operations. Under Test Conditions and Procedures for each test section, the total amount of test traffic applied to the test section is given in terms of total number of passes of the vehicle per operating gross weight and the corresponding converted equivalent 18,000-lb, single-axle, dual-wheel load operations.

This was done to facilitate drainage and to reduce the effort required for subgrade construction. Both test sections were constructed on a longitudinal grade of 0.15 percent from north to south. Transverse grades were established to provide a 3.33 percent crown for the flexible pavement test section and a 2 percent slope from east to west for the rigid pavement test section. Shallow ditches were provided on either side of the flexible pavement test section for drainage, and the existing ditches were utilized to drain the rigid pavement test section. A bituminous transition was constructed between the two test sections, and maneuver areas were constructed at the south end of the rigid and north end of the flexible pavement test sections.

22. A plan and profile of the rigid and flexible pavement test sections are shown in Figures 1 and 2, respectively. The portland cement concrete test section was 397 ft long by 22 ft wide and consisted of six items. The 6-in.-thick concrete mix in item 1 and the 4-in.-thick concrete mix in the remaining five items were placed on an existing 4-in.-thick base course. The bituminous concrete test section was 550 ft long and 24 ft wide and consisted of 13 test items. The total pavement thickness of the bituminous test section was 9 in., and consisted of 3 in. of bituminous mix and 6 in. of lime-stabilized base material. A description of the various pavement elements is given in the following paragraphs.

## Pavement Elements

### Lean clay subgrade

23. The natural soil at the test site was utilized for the subgrade. The soil has a liquid limit (LL) of 34 and a plasticity index (PI) of 12 and classifies as a lean clay (CL) according to the Unified Soil Classification System (USCS).[6] Classification data are shown by curve 1 in Figure 3.

### Stabilized base course

24. A gravelly-clayey sand (SC) lime-stabilized base course, 6 in. thick, was constructed for all 13 items of the flexible pavement test

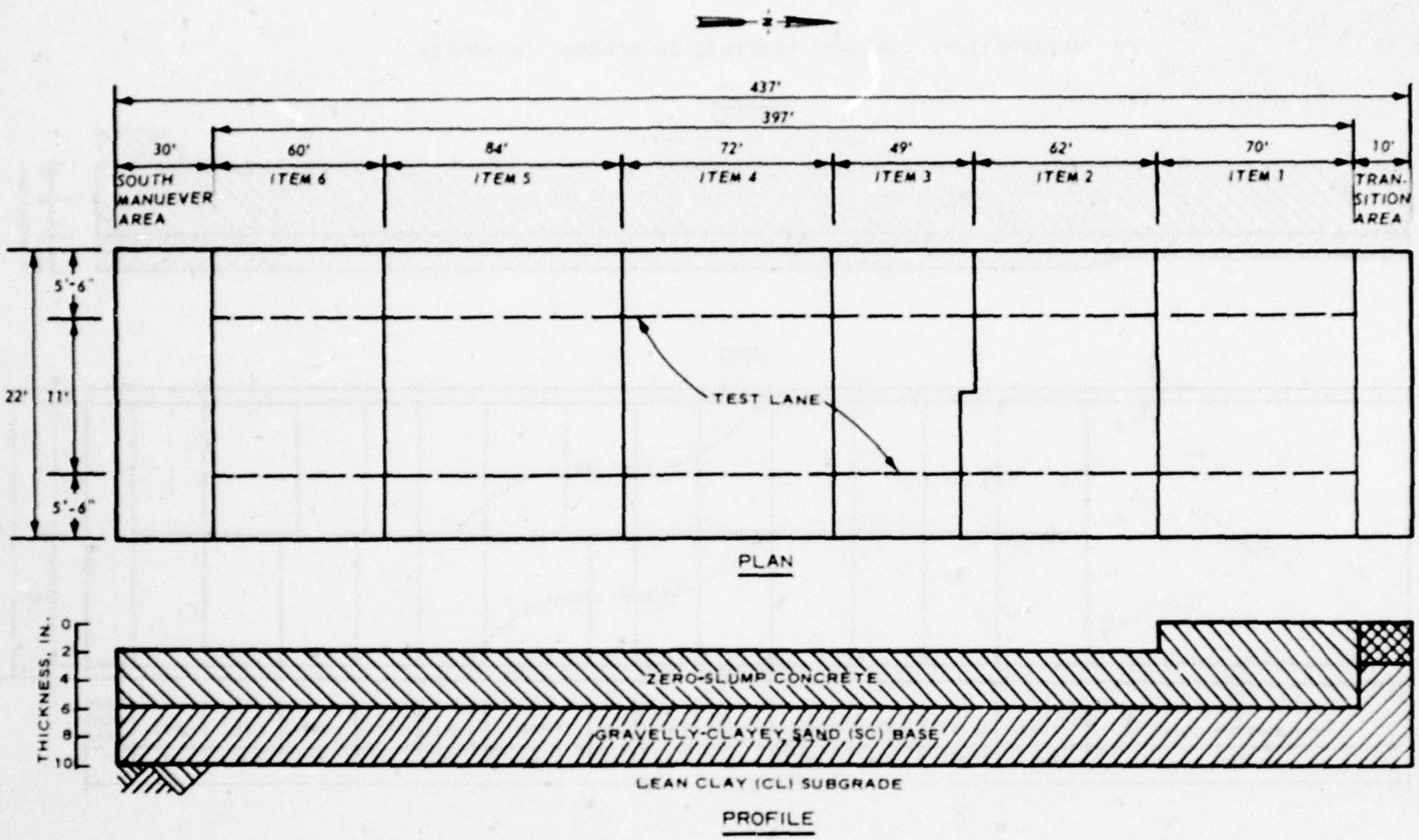



Figure 1. Layout of rigid pavement test section

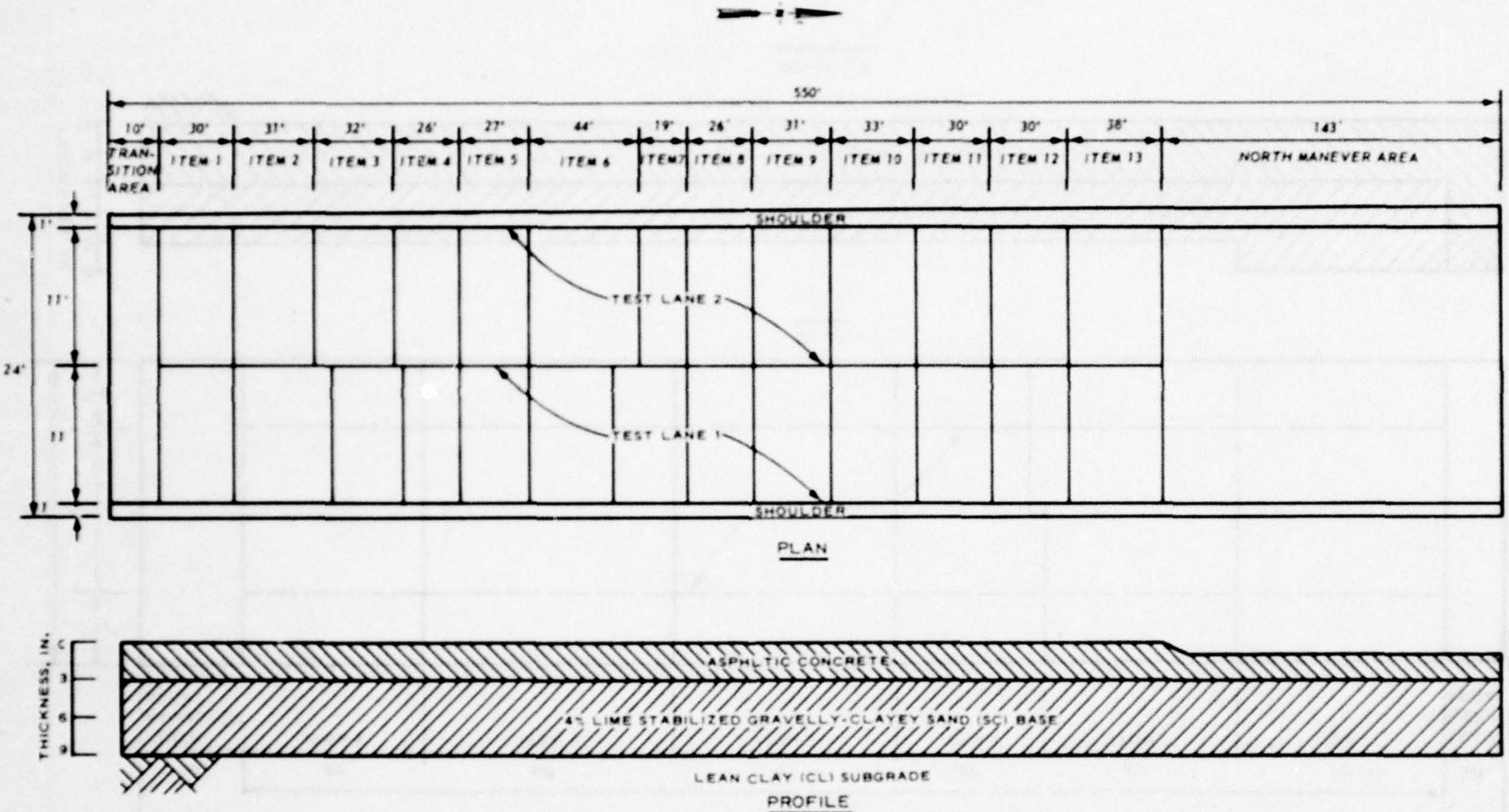
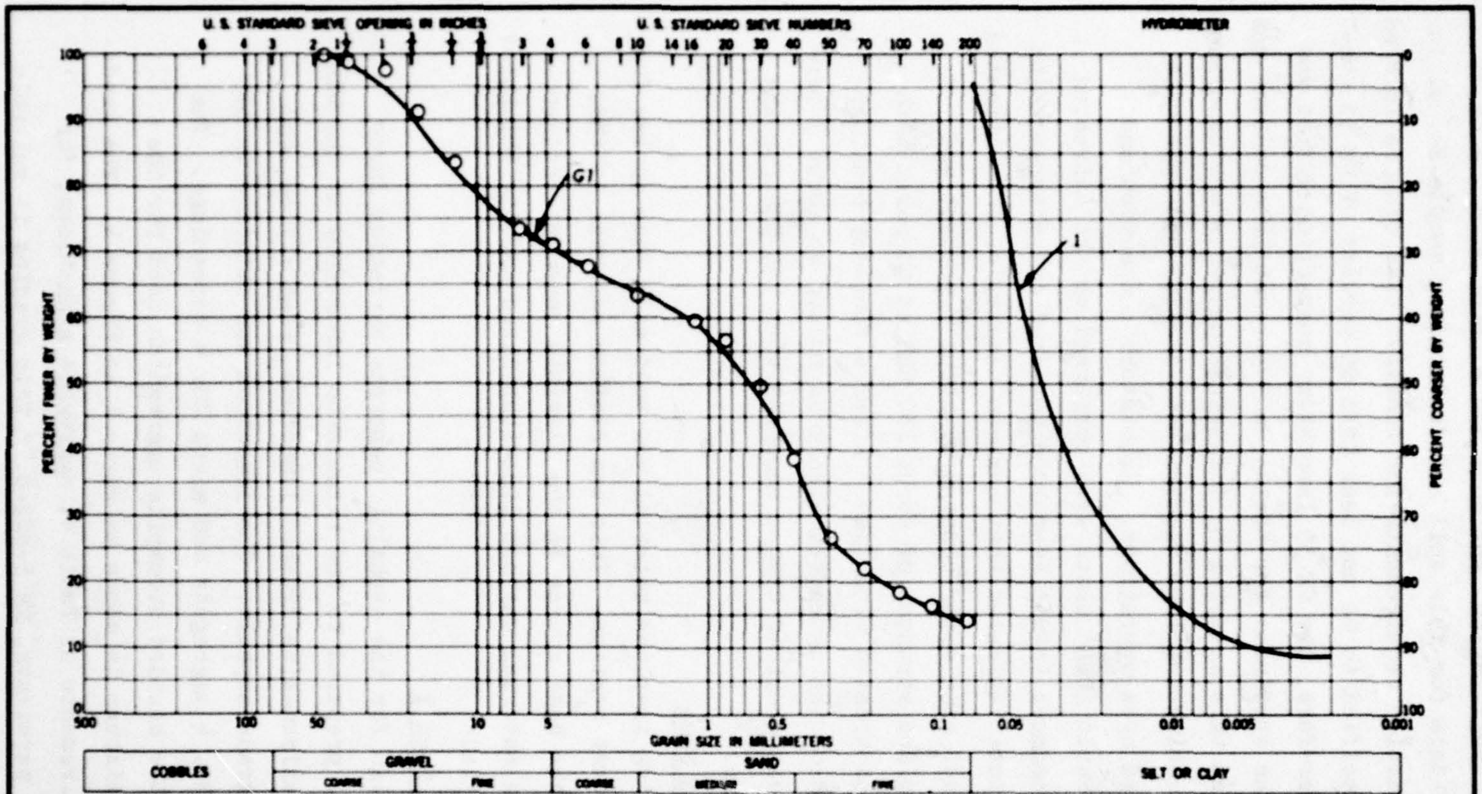



Figure 2. Layout of flexible pavement test section




| Sample No. | MATERIAL | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 1 | SUBGRADE | LEAN CLAY (CL) | | 34 | 22 | 12 |
| G1 | BASE | GRAVELLY-CLAYEY SAND (SC) | | 37 | 13 | 24 |

Project
CLASSIFICATION DATA
Area
Boring No.
Date

GRADATION CURVES

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Figure 3. Classification data for subgrade and base materials

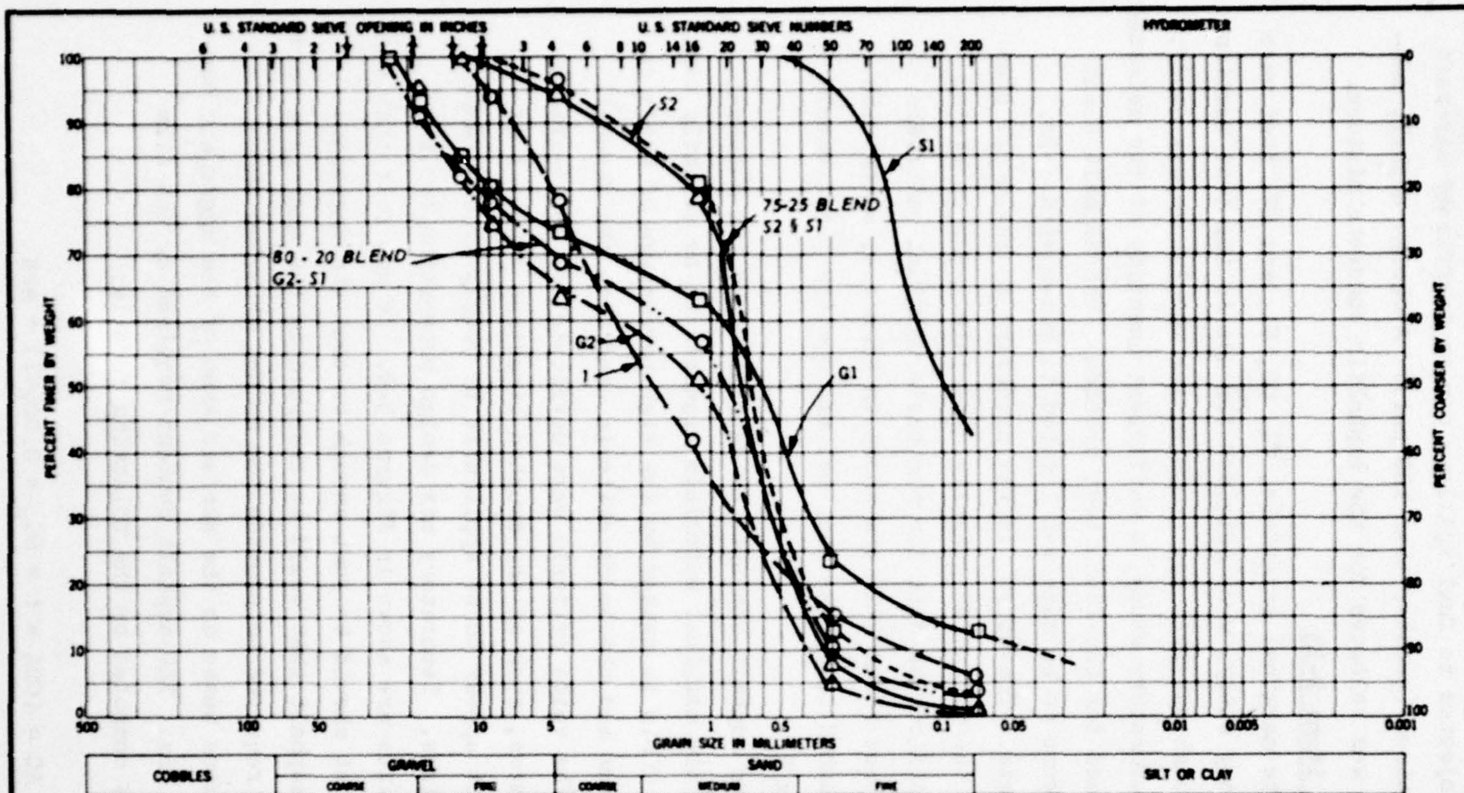
section. Prior to stabilization, the soil had a LL of 37 and a PI of 24. Classification data for this soil are depicted as sample No. G1 in Figure 3. The compaction requirements for cohesive base courses in road construction are specified to be not less than 95 percent of CE 55 compaction effort;[4] therefore, the CE 55 laboratory compaction effort was used in preparing the specimens for tests. A 4 percent lime content was selected to stabilize this material by following the procedure described in Reference 7 for estimating lime requirements of soil and aggregate materials for forward area operations. Laboratory compaction and California Bearing Ratio (CBR) tests were performed on the untreated and lime-treated specimens in the as-molded unsoaked and after-soaking conditions. These data indicated that maximum density of the untreated specimens was obtained at a water content of about 7 percent and resulted in an as-molded strength of about 150 CBR as compared with 305 CBR for specimens treated with lime. After a four-day soaking period, the strength of the untreated specimens molded at about 7 percent water content was about 60 CBR as compared with 230 CBR for the lime-treated specimen.

Gravelly-clayey sand base

25. The existing in-place material was used as a base course for the rigid pavement test section. This was similar material to that which was used for the base course in the flexible pavement test section. However, this material was not lime-stabilized and its thickness was approximately 4 in.

Asphaltic concrete, item 1

26. A mix design for the asphaltic concrete surfacing layer placed in item 1 was prepared in the bituminous laboratory at the WES utilizing 3/4-in. maximum-size crushed limestone, sand filler, and 85-100 penetration grade asphalt. The limestone was obtained in two sizes: 3/4-in. to No. 4 aggregate and minus No. 4 screenings. The gradation curve of the blended stockpile aggregates used for the asphaltic concrete mixture is shown as curve 1 in Figure 4. The gradation meets the requirements of Table 4; aggregate gradations, for bituminous concrete pavements, TM 5-822-8.[2] This grading is suitable




| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI |
|---|---|---|---|---|---|---|
| 1 | | CRUSHED LIMESTONE (GW) | | | NONPLASTIC | |
| G1 | | GRAVELLY-CLAYEY SAND (SC) | | 37 | 13 | 24 |
| G2 | | GRAVELLY SAND (SP) | | | NONPLASTIC | |
| S1 | | CLAYEY SAND (SC) | | 23 | 14 | 9 |
| S2 | | SAND (SP) | | | NONPLASTIC | |

**GRADATION CURVES**

Project GRADING CURVES

Area BITUMINOUS MIX AGGREGATES

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Figure 4. Grading curves of bituminous mix aggregates

for conventional bituminous concrete on roads, streets, and heliports or airfields not subjected to fuel spillage nor to traffic by aircraft with high-pressure tires (greater than 100 psi). A design asphalt content of 5.7 percent was selected for the asphaltic concrete mixture.

Asphaltic concrete, items 2-13

27. Four of the marginal materials, G1, G2, S1, and S2, that were used in the laboratory study, were selected for use in the test section. Originally, only enough material was procured for the laboratory study; and following the laboratory study, a sufficient quantity of the selected materials was obtained for the field test section. The asphalt plant in which the mixes were to be made was limited to mixes with 1-in. maximum-size aggregate. Therefore, it was necessary to scalp all plus 1-in. material from the G1 and G2 gravelly materials prior to mixing in the plant. Classification data for the basic marginal materials and blends used in test items 2-13 are shown in Figure 4, along with the high-quality crushed limestone that met all quality requirements and was used in item 1.

28. The optimum asphalt contents as determined by the Marshall design criteria for the marginal materials appeared to be slightly high for the sand mixes. This is caused by the high percentage of voids in the mineral aggregates and the voids criteria used with the Marshall method of design. The voids criteria were developed for dense-graded high-quality aggregates, such as the crushed limestone (curve 1 of Figure 4), but do not appear to be applicable to poorly graded sands with little or no fines. Laboratory mix design properties for the marginal material mixes are shown in Figures 5-9. It was felt that the proper asphalt content should be just enough to coat the aggregate particles plus the asphalt that would be absorbed in the aggregate pores. The asphalt content required to provide the amount absorbed and a 6-micron film thickness based on the surface area of the aggregate was calculated for each mix. The asphalt content required by the film thickness method was computed by the following formula:

$$AC = (CSA \times t \times SG_B \times 0.02047) + ABS$$

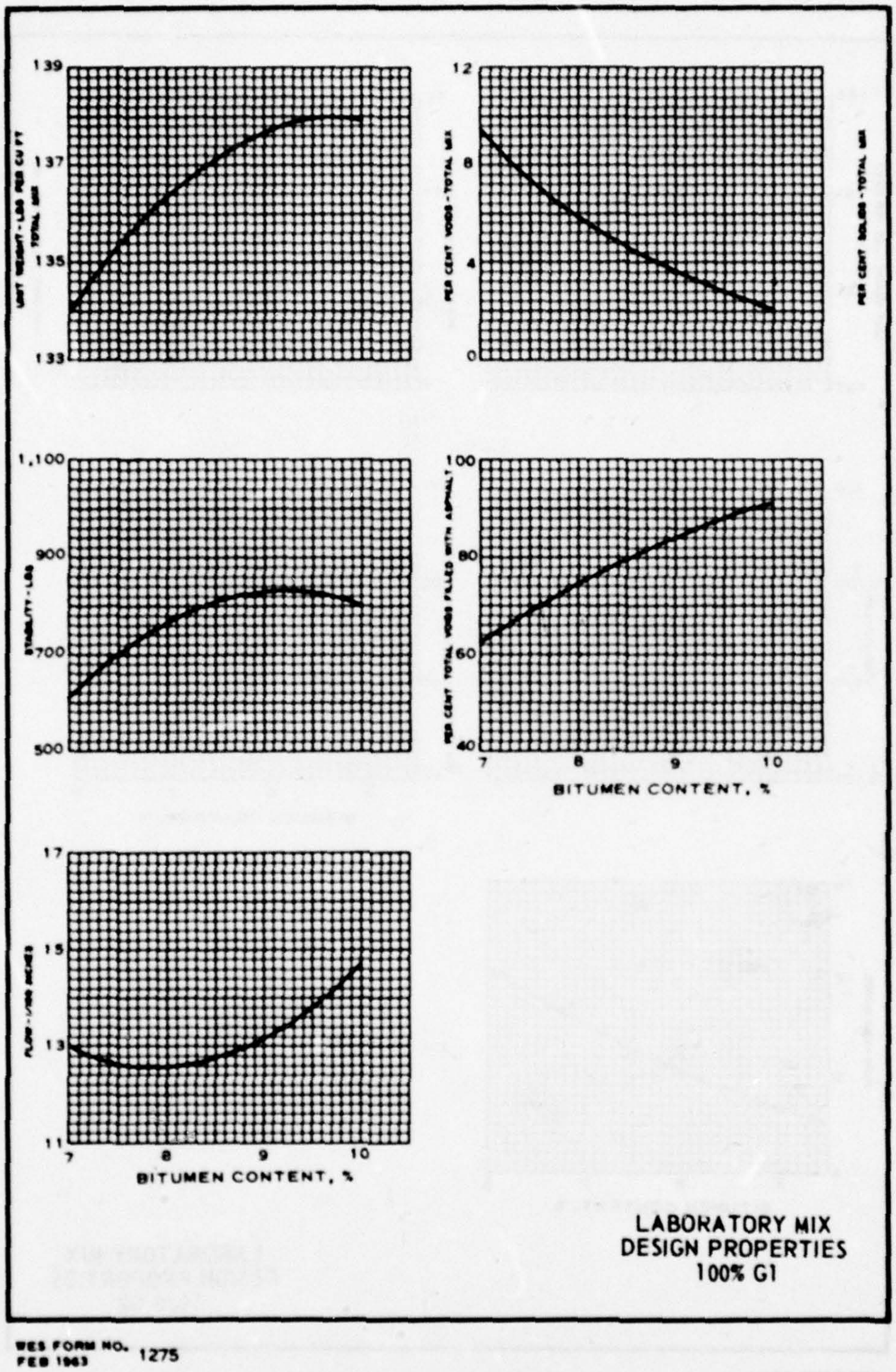


Figure 5. Laboratory mix design properties 100 percent G

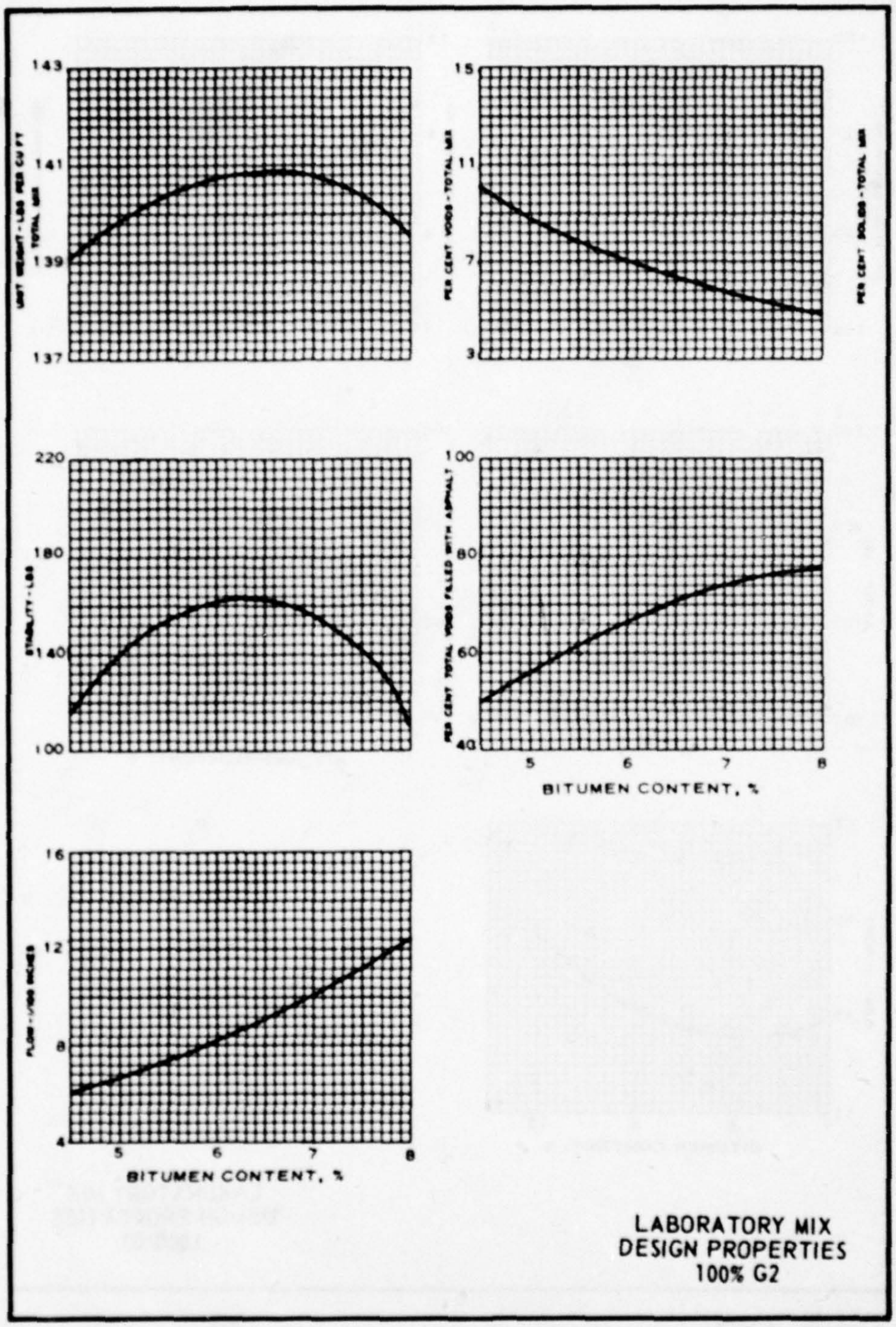


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Figure 6. Laboratory mix design properties 100 percent G2

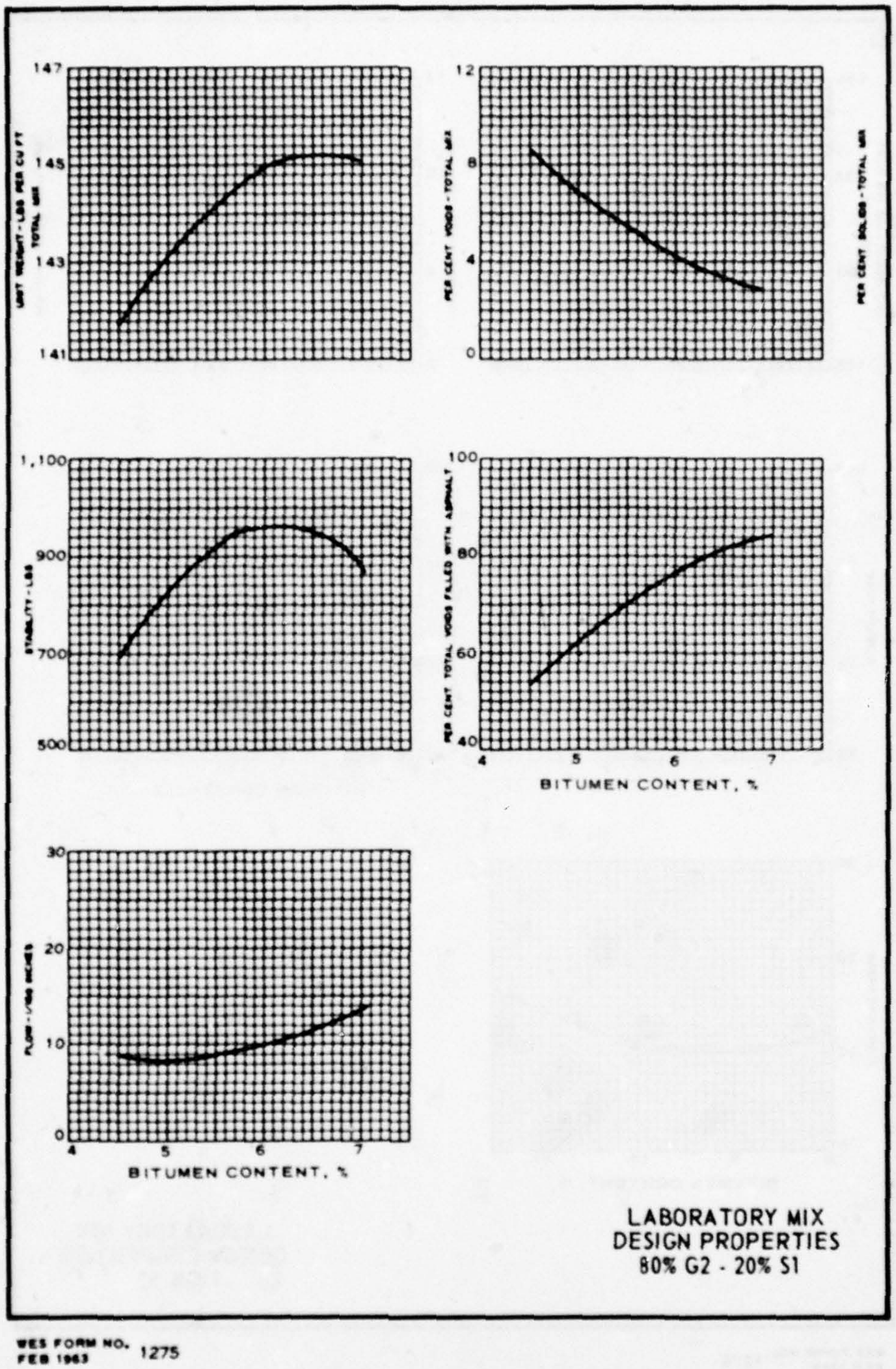


Figure 7. Laboratory mix design properties 80 percent G2-20 percent S1

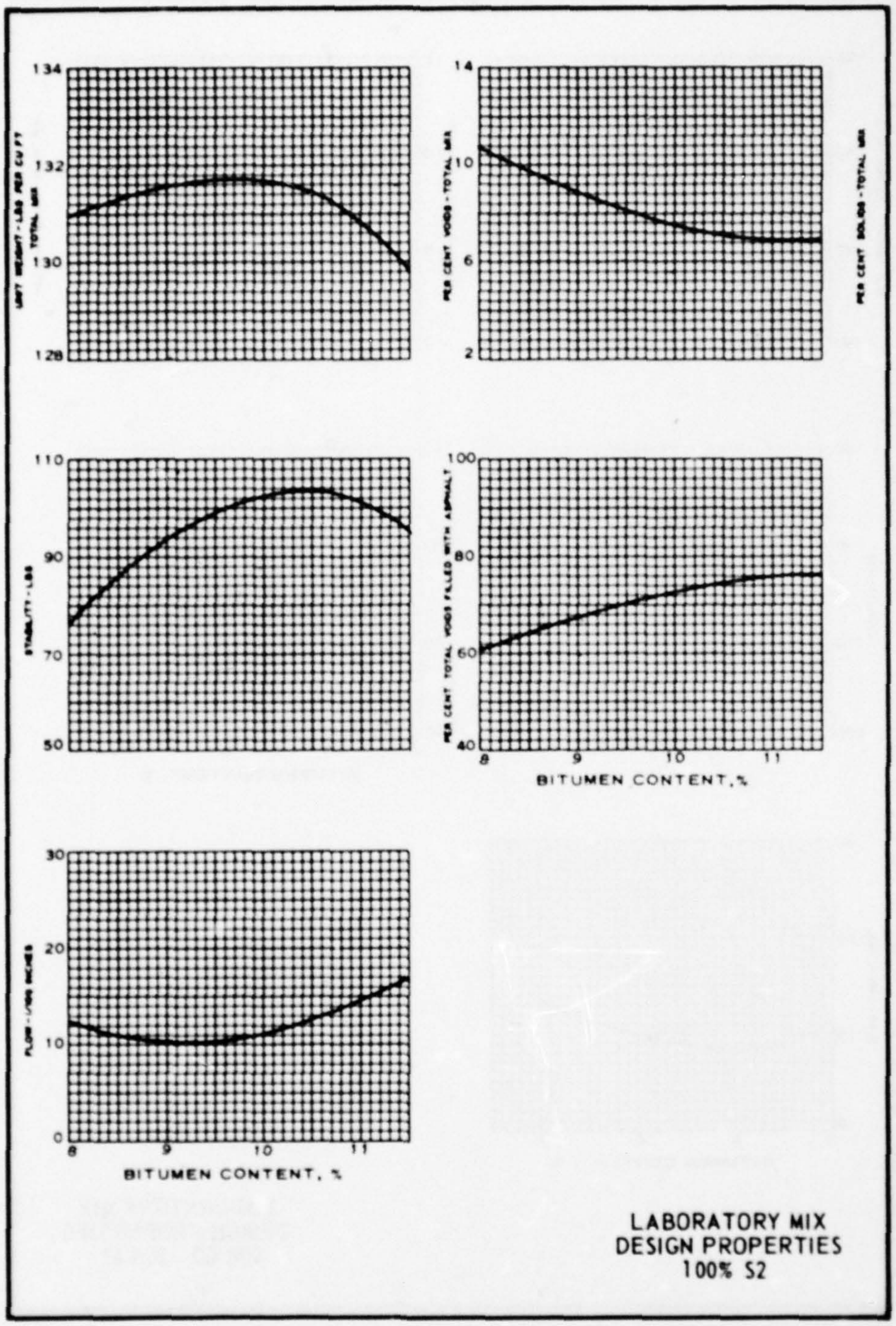


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Figure 8. Laboratory mix design properties 100 percent S2

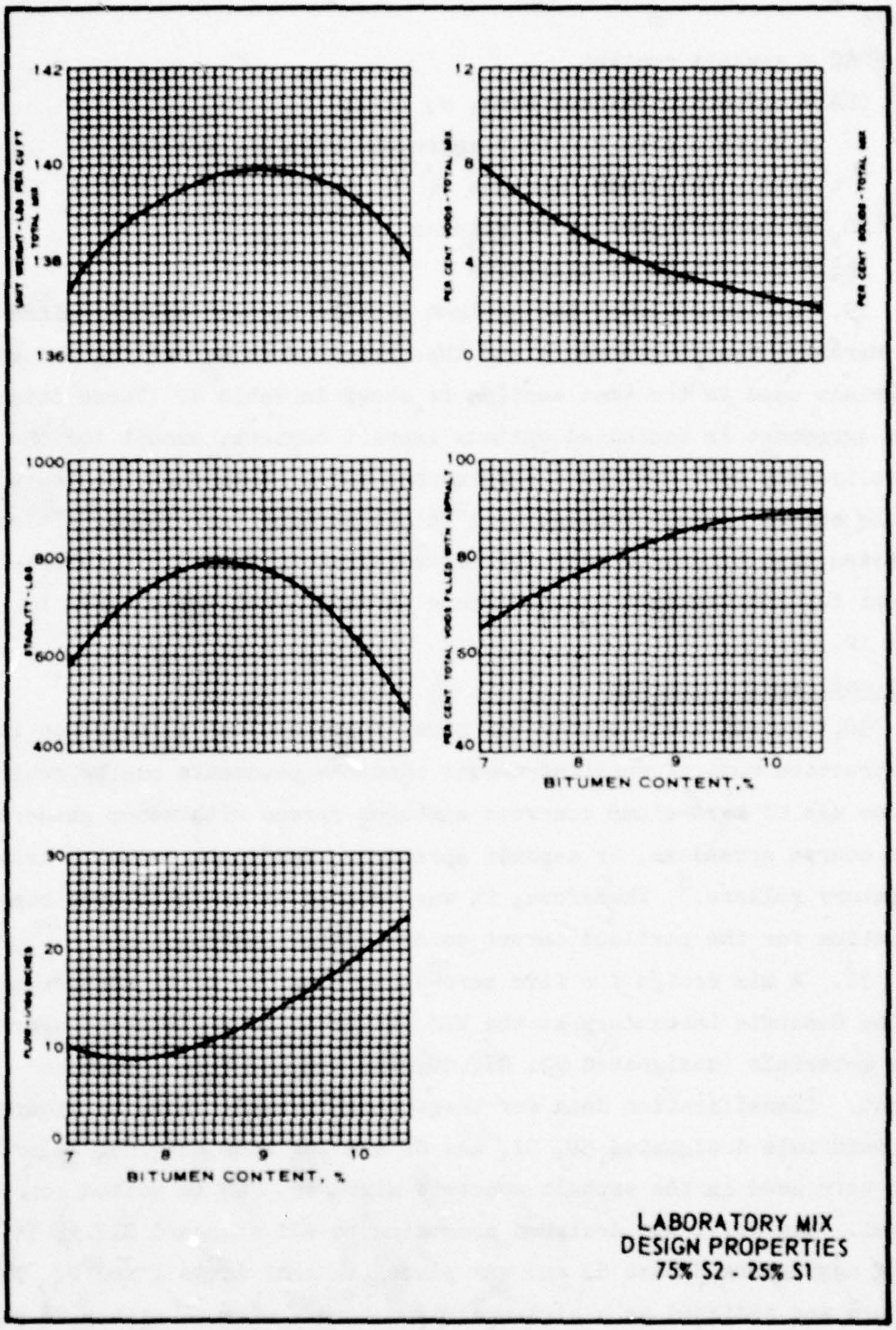


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Figure 9. Laboratory mix design properties
75 percent S2-25 percent S1

where:

AC = asphalt content

CSA = corrected surface area, sq ft/lb

= surface area × 2.65 + aggregate specific gravity

t = film thickness, microns

$SG_B$ = specific gravity of bitumen

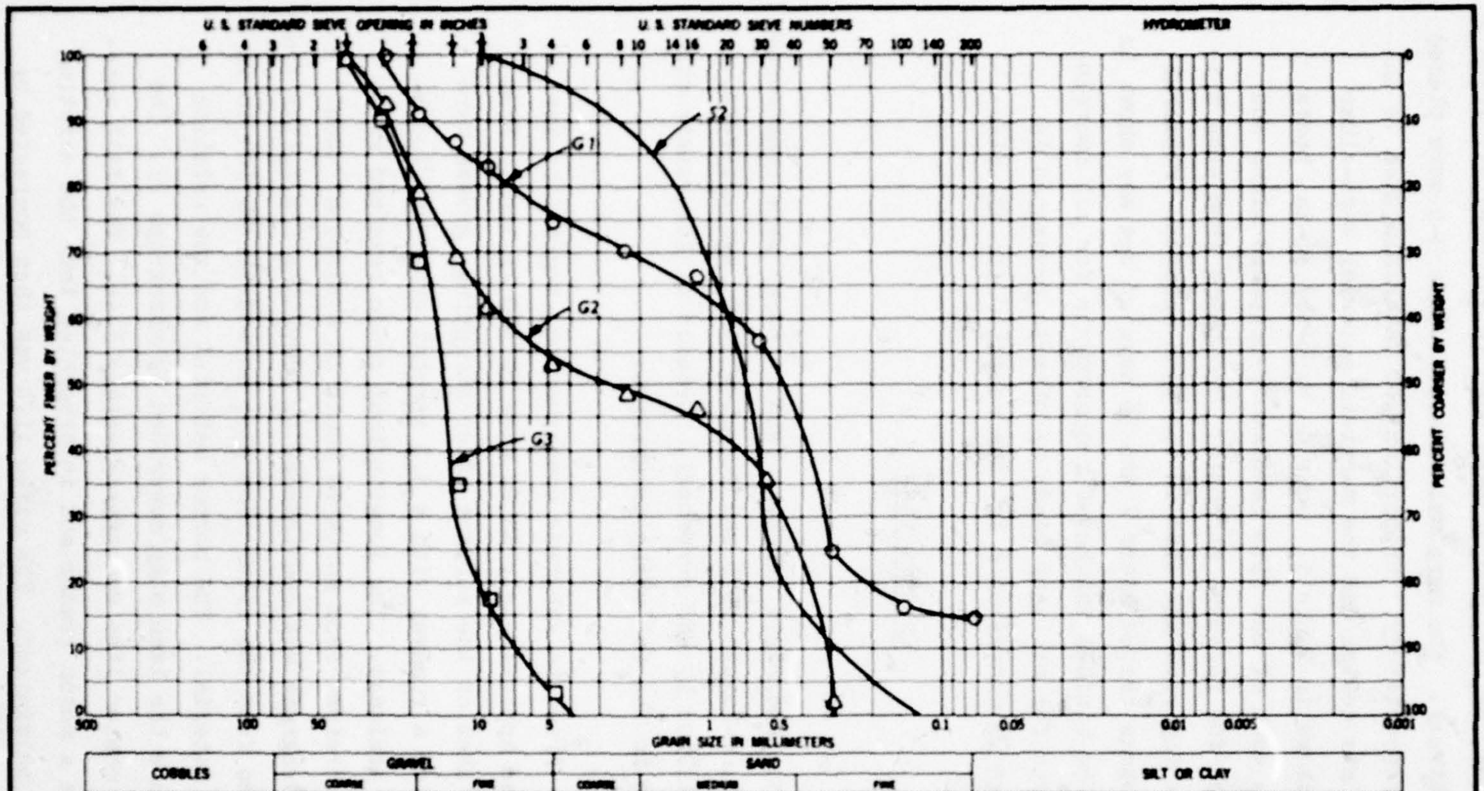
ABS = absorption of aggregate

29. A comparison of the optimum asphalt content as determined by the Marshall design procedure and the surface area method for the various materials used in the test section is shown in Table 4. These data show fair agreement in indicated optimum asphalt content, except for the gravelly sand (G2) and the concrete sand (S2). Also shown in the table is the actual asphalt content used in the various test items. It can be noted that a range of asphalt contents was used with all materials, except for the standard crushed stone in item 1 and the sand S2 in item 10.

Portland cement concrete

30. Recent tests at the WES have indicated that a reduction in construction cost of portland cement concrete pavements can be realized by the use of zero-slump concrete mixtures spread with motor graders, base course spreaders, or asphalt spreaders, and compacted with heavy vibratory rollers.[8] Therefore, it was decided to use this type construction for the portland cement concrete test section.

31. A mix design for five zero-slump concrete mixes was prepared in the Concrete Laboratory at the WES utilizing four different aggregate materials (designated S2, G1, G2, and G3) and Type 1 portland cement. Classification data for these materials are shown in Figure 10. The materials designated S2, G1, and G2 are the same marginal materials that were used in the asphalt concrete mixtures. G3 is washed concrete gravel. Mix No. 1 was designed according to ACI Standard 211.13-75[5] using aggregates S2 and S3 and was placed in test items 1 and 2. This mixture was designed as a high-quality concrete mixture with a 28-day flexural strength of 750 psi that required 517 lb of cement per cubic yard. Mixes 2-5 were designed using the same cement factor as for mix 1.




| Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | PI | |
|---|---|---|---|---|---|---|---|
| S2 | | POORLY-GRADED SAND (SP) | | | NP | | Project |
| G1 | | GRAVELLY-CLAYEY SAND (SC) | | 37 | 13 | 24 | |
| G2 | | GRAVELLY SAND (SP) | | | NP | | Area |
| G3 | | POORLY-GRADED GRAVEL (GP) | | | NP | | |
| | | | | | | | Boring No. |
| GRADATION CURVES | | | | | | | Date |

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Figure 10. Grading curves, zero-slump mix aggregates

Aggregate materials G2, S2, G3, and G1 were used in the marginal mixes 2, 3, 4, and 5, respectively. The marginal material mixes 2-5 were placed in test items 3-6, respectively. Proportions of materials used in the laboratory standard mix design and the marginal material zero-slump concrete mixes are shown in Table 5. Four 6- by 6- by 36-in. beams were fabricated from each of the five laboratory-prepared mixes and then cured and tested for flexural strength. Two beams from each mixture were cured in a fog room and also in wet sand outside. Flexural strengths of these beams tested after 7 and 28 days of age are shown in Table 6. Based on the minimum thickness requirements for all nonreinforced rigid pavements for military roads or streets presented in TM 5-822-6,[3] a design thickness of 6 in. was selected for all mixes.

## Construction

### General

32. The flexible and rigid pavement test sections were constructed during the periods June-August 1976 and December 1976, respectively. All work was accomplished by WES personnel. Details of the construction operations are given in the following paragraphs.

### Flexible pavement

33. Subgrade. Prior to subgrade construction, vegetation was stripped from an area approximately 50 ft wide by 550 ft long. From cross-section data taken on the surface after stripping, grades were established to provide a roadway with a 3.3 percent crown and longitudinal ditches for drainage. The longitudinal grade remained relatively the same and drained from north to south on a slope of about 0.15 percent. The subgrade was constructed by elevating the center line with the soil removed from the ditch line plus an additional 100 cu yd of lean clay borrow material. The borrow material and the existing subgrade material were the lean clay described in paragraph 23. The average fill at the center line was approximately 5 in. The fill material was spread with a motor grader and incorporated into the existing surface by use of a pulvimixer. The mixed lift was then compacted by

applying eight coverages of a self-propelled, seven-wheel, rubber-tired roller loaded to 47,000 lb and having a tire inflation pressure of 90 psi. After the compacted layer had been tested to determine water content, density, and CBR, it was fine-bladed to the desired elevation and sealed with the rubber-tired roller. The average strength of the top 12 in. of subgrade was about 23 CBR (Table 7). A view of the finished subgrade is shown in Photo 1.

34. Stabilized base. The base course consisted of a 6-in.-thick compacted layer of lime-stabilized gravelly-clayey sand. The gravelly-clayey sand is the same material described in paragraph 24. Prior to applying the lime, the gravelly-clayey sand was hauled in by dump truck and dumped onto the subgrade, spread to grade with a motor grader, and then pulvimixed into one 8-in.-thick loose layer, which resulted in a 6-in.-thick compacted layer. After initial pulvimixing, bags of lime were placed at predetermined intervals (Photo 2) to give the desired 4 percent rate of stabilization. The lime was then spread over the surface of the loose material and pulvimixed (Photo 3). Water was added and then thoroughly mixed with the lime and soil to a depth of about 8 in. After final mixing, the entire layer was compacted. The water content of the mixture prior to compaction was about 11 percent. Initial compaction was accomplished with two coverages by a D-4 dozer to prevent ruts by the heavy roller, and then final compaction was with eight coverages by a 50-ton, four-wheel, rubber-tired roller with a tire inflation pressure of 100 psi. The compacted base was then fine-bladed with a motor grader, sealed with two coverages by the self-propelled roller, and primed with approximately 0.3 gal/sq yd of MC-1 cutback asphalt. The average as-constructed water content of the stabilized base after curing for 48 hr was 5.9 percent, which resulted in a dry density of 135.1 pcf and a CBR of above 150 (Table 7).

35. Asphaltic concrete. The bituminous surface mixes for the flexible pavement test section were mixed and placed during the period 23-30 August 1976. These mixtures were made in a continuous hot-mix plant at the WES. The maximum size aggregate this plant will mix is 1 in.; therefore, aggregates G1 and G2 were screened to remove all

plus 1-in. material prior to mixing. It was originally planned to include mixes made with the pit run clayey sand material designated S1. However, attempts to mix this material, which had in excess of 40 percent finer than a No. 200 sieve, were unsuccessful. Because of the larger amount of dust in the material, the return screw from the dust collector would clog and completely freeze. Therefore, this material was used only as a filler with the G2 gravel and S2 sand. The mixing temperature for all mixes ranged from about 250° to 300° F; and since the haul from the plant to the test site was short, the temperatures at laydown were about the same as the mixing temperature. Prior to laydown, samples were obtained from each mix for laboratory extraction, gradation, and compaction tests. The results of the laboratory tests on the various mixes are summarized in Table 8. The mixes were placed with an asphalt finisher in two 11-ft-wide longitudinal lanes (Photo 4). During laydown, the mixes with the same gradation were placed in both lanes before advancing to the adjacent item, which contained a different mix. This procedure was followed to reduce the time and effort required to calibrate the mixing plant for the different mixes. All mixes were placed in one 3-in.-thick layer. Compaction was obtained by breakdown rolling with a 12-ton tandem steel-wheel roller (Photo 5) and then with eight coverages by the self-propelled, seven-wheel, rubber-tired roller loaded to 47,000 lb and having a tire pressure of 90 psi (Photo 6). Final rolling was accomplished with the tandem steel-wheel roller. In some instances, initial efforts to compact the mixes at normal rolling temperatures of 250° F or above were unsuccessful because of the low stability of the mix. Therefore, the mix was allowed to cool before rolling. The rolling temperatures of the various marginal material mixes ranged from about 130° to 240° F (Table 9). After compaction, cores were cut and tested for asphalt content and density. A summary of these data is also shown in Table 9.

Rigid pavement

36. Subgrade and base. The zero-slump mixes were placed on an existing unsurfaced gravel road, which required blading of the gravel to grade prior to placement of the concrete. The subgrade of this road

was constructed several years ago from the same lean clay material described in paragraph 24. The average water content and strength of the top 12 in. of this subgrade material were about 15 percent and 50 CBR, respectively. These measurements taken after traffic are shown in Table 10. Although these measurements were taken after traffic, there should be very little difference between the before- and after-traffic water content and strength measurements due to the age of the road. The gravelly material, which classified as a gravelly-clayey sand, was fine-bladed with a motor grader to provide a transverse slope of 2 percent from east to west and then rolled with six coverages by the self-propelled, seven-wheel, rubber-tired roller loaded to 47,000 lb with a tire pressure of 90 psi. Plate bearing and thickness measurements were made on the finished base material in items 2 and 5 immediately prior to paving operations. The modulus of soil reaction k values ranged from 435 pci in item 5 to 714 pci in item 2. The average thickness of the base course was about 4 in.

37. Zero-slump concrete. The five zero-slump mixes described in paragraph 31 were mixed in 2-cu-yd batches in a stationary batch plant at the WES and then transported in dump trucks to the test site for placement and compaction. The concrete in test item 1 was placed by end dumping the concrete mix onto the surface of the base and then spreading the mix with a motor grader. The concrete in all other test items was placed with an asphalt finisher. No special effort was made to provide transverse contraction joints between the items or a longitudinal joint at the center line of the test section. A tandem vibratory roller was used to compact all mixes.

38. The end-dumped concrete mix in item 1 was fine-bladed with a motor grader to an uncompacted lift thickness of approximately 7-1/2 in. Due to the small volume per load (2 cu yd) and the short length of the test item (70 ft), it was difficult to obtain a smooth surface with the motor grader. However, after compaction, the surface of the concrete was fairly smooth as depicted in Photo 7.

39. The zero-slump mixes in items 2-5 were placed in a single 6-in.-thick uncompacted lift with an asphalt finisher (Photos 8 and 9).

The mixes were placed in two adjacent 11-ft-wide lanes. Compaction of the concrete mixture was started as soon as the mix had been placed in one lane the entire length of the item. The small capacity of the mixer plus breakdowns of the mixer resulted in a time lag of 1-2 hr from start of concrete placement in an item until commencement of compaction in that item.

40. The mix in item 6 was placed in two lifts, each of which was approximately 2-1/2 in. thick. Placement of the top lift directly on the uncompacted surface of the bottom lift resulted in a total uncompacted lift thickness of about 5 in. Compaction was begun immediately after placement of the top lift. The mix was placed in this item in two lifts because of the low stability of the mix and concrete buildup on the underside of the screed. This concrete buildup added weight to the screed and resulted in a maximum lift thickness of about 2-1/2 in. that the finisher was capable of placing.

41. A 25,000-lb Bomag BW220R tandem vibratory roller (Photo 10) equipped with two 80-in.-wide drums was used to compact all mixes. During vibratory compaction, the roller was operated at a frequency of 2,400 vibrations per min (vpm) and the total applied force (operating weight plus dynamic force) per drum ranged from 23,375 to 36,125 lb. This roller was also operated statically or with no vibration. The same rolling pattern was used during static and vibratory compaction. The rolling pattern used is described in the following manner. The roller was started with one edge of the drum extending slightly over the outside edge of the first 11-ft-wide lane of concrete placed and then traveled in the forward direction to the end of concrete placement, where it was stopped and reversed; it then returned in the same track. The roller was then shifted laterally to approximately 6 in. from the opposite edge of this 11-ft-wide lane, and the same procedure was followed. After placement of the second lane of concrete, the roller was shifted laterally with its drum extending slightly over the outside edge of this adjacent 11-ft-wide lane of freshly placed mix and then traveled in the forward direction to the end of concrete placement, where it was stopped and reversed; it then returned in the same track. The roller

was again shifted laterally, so the drums would cover the remaining uncompacted portions of both paving lanes. The roller then traveled forward and backward in the same track. This pattern resulted in two passes by the roller over the entire 22-ft-wide roadway with some overlap in the center of the 11-ft-wide paving lanes and at the longitudinal joint of the two paving lanes.

42. The compaction effort applied to each of these zero-slump mixes was based on visual consolidation of the mix during rolling and upon the results of previous tests[1] performed at the WES to determine the effectiveness of vibratory and static rollers in the compaction of zero-slump concrete. Generally, when there appeared to be good consolidation of the mix or a tendency for shoving or displacement of the mix, rolling was stopped. The following four paragraphs describe the various compaction efforts used to compact the five different mixes placed in this study.

43. The mixes placed in items 1, 2, and 3 were compacted with two passes by the roller and then two additional passes by the roller vibrating. During vibratory compaction, the total applied force per drum was 36,125 lb. Photos 11, 12, and 13 show a closeup view of the pavement surface after compaction in items 1, 2, and 3, respectively. The slurry that filled some of the surface voids in item 1, as indicated in Photo 11, was a result of light rain during vibratory compaction of the mix.

44. Mix 3, which was placed in item 4, was compacted with four passes by the roller operating at a total applied force of 23,375 lb per drum. Higher force levels than 23,375 lb per drum during vibratory compaction of this mix resulted in excessive flow or lateral movement of the mix. The roller was operated at maximum speed (6 mph) in the first concrete placement lane and at about 1 mph in the second placement lane. The operating speed was decreased because the maximum operating speed resulted in a rough surface after compaction (Photo 14). Photo 15 shows the surface texture of the second placement lane after compacting the mix with the roller operating at a speed of about 1 mph.

45. The mix placed in item 5 was compacted with only two passes by the roller operating at a total applied force of 23,375 lb. The concrete mixture appeared quite stable under the roller at this force level. However, at greater force levels or with additional passes by the roller at the 23,375-lb force level, raveling would occur at the surface. The aggregate used in this concrete mixture provided a very open-textured surface after compaction (Photo 16).

46. The mix placed in item 6 (mix 5) was first compacted with two passes by the vibratory roller operated at a total applied force of 23,375 lb and then with an additional two passes by the roller used as a static roller. Static rolling was applied after vibratory compaction to smooth out the checked surface, which resulted during vibratory compaction. A view showing the surface texture of this mix after final rolling is shown in Photo 17.

47. Curing was accomplished by covering the concrete for 28 days with polyethylene. Prior to covering the concrete with the polyethylene sheets, the surface of the concrete was wet with a fine spray of water.

48. Two 6- by 6- by 36-in. test specimens representative of the concrete placed in each test item were cast at the jobsite during concrete placement. These specimens were compacted in the field with a vibratory plate compactor and then field-cured in the same manner as was the pavement. At 26 days of age, the specimens were transferred to the WES Concrete Laboratory and placed in limewater. Then, at 28 days of age, flexural strength tests were conducted on the specimens. The average flexural strengths of the concrete mixtures placed in items 1-6 were 750, 750, 685, 590, 350, and 125 psi, respectively.

# PART IV: TESTING AND BEHAVIOR UNDER TRAFFIC - FLEXIBLE PAVEMENT

## Test Conditions and Procedures

### General

49. Traffic tests were performed on two separate lanes of the 22-ft-wide and 397-ft-long test section. The test vehicles, test lanes, traffic patterns, pavement conditions, and failure criteria are discussed in the following paragraphs.

### Test vehicles

50. Traffic was applied to the test section with a pneumatic-tired vehicle and two-tracked vehicles. The primary test vehicle was an M51 5-ton dump truck (Photo 18). All the wheels on the truck were equipped with 11.00×20, 12-ply rating tires inflated to 70 psi. This vehicle was operated at gross loads of 40,920, 41,145, 43,900, and 48,695 lb. The gross load of the truck was increased so that the behavior of the pavement under traffic could be determined under a reasonable number of passes by the test vehicle.

51. Tracked-type vehicle traffic was applied using an M113 armored personnel carrier and an M48A1 tank. The M113 and M48A1 were operated at gross weights of 19,000 and 103,210 lb, respectively. Photo 19 shows the track configuration of the personnel carrier, and Photo 20 depicts the track configuration of the tank.

### Test lanes and traffic patterns

52. Figure 2 shows the location, width, and length of the two test lanes. Pneumatic-tired-type traffic was applied to both test lanes to determine the effect of pavement temperature on the performance of the marginal material asphaltic concrete. Traffic was applied to lane 1 only when the pavement temperature was 80° F or below and in lane 2 when the pavement temperature was 80° F or higher. After completion of the pneumatic-tired traffic in lane 2, the pavement was subjected to tracked-type traffic at various pavement temperatures.

53. Traffic was applied with all test vehicles in the same manner.

A vehicle was operated in one direction until it had traveled the entire length of the test section where it was reversed; it then returned in the same wheel or track path. This resulted in a total of two passes by the test vehicle for each round trip of test traffic. The traffic levels referred to in this report were computed by converting the number of passes of test traffic applied to the pavement to equivalent 18,000-lb, single-axle, dual-wheel load operations through use of equivalent operations factor curves.[4] The M51 dump truck was operated at equivalent 18,000-lb, single-axle, dual-wheel loads of 2.9, 3.5, 5.1, and 12, while the M113 personnel carrier and the M48A1 tank were operated at equivalent 18,000-lb, single-axle, dual-wheel loads of 0.4 and 2,500, respectively. The total amount of test traffic applied to test lanes 1 and 2 was as follows:

| | | Test Traffic | | | |
|---|---|---|---|---|---|
| | Gross | Lane 1 | | Lane 2 | |
| Test Vehicle | Weight lb | No. of Passes | Equivalent 18-kip Single-Axle Loads | No. of Passes | Equivalent 18-kip Single-Axle Loads |
| M51 | 40,920 | 5,008 | 14,323 | | |
| M51 | 41,145 | 1,750 | 6,125 | | |
| M51 | 43,900 | 310 | 1,575 | | |
| M51 | 48,695 | 1,010 | 12,120 | 8,896 | 106,752 |
| M113 | 19,000 | 326 | 130 | 326 | 130 |
| M48A1 | 103,210 | 20 | 50,000 | 20 | 50,000 |

Pavement temperature

54. Pneumatic-tired traffic was applied to the two traffic lanes of the test section during the period 22 September 1976-30 July 1977. During trafficking, the average pavement temperature, as determined from measurements at the surface and the bottom of the asphaltic concrete layer, ranged between 40° and 133° F. The traffic and pavement temperature-distribution curves for both test lanes (Figure 11) were derived from traffic and pavement temperature records made hourly during traffic testing. As noted in Figure 11, no traffic was applied to lane 1 (cold weather traffic) when the pavement temperature was 80° F or greater. To compare the behavior of the marginal material bituminous mixes under the same type of traffic but at a higher pavement temperature, traffic was applied to lane 2 when the pavement

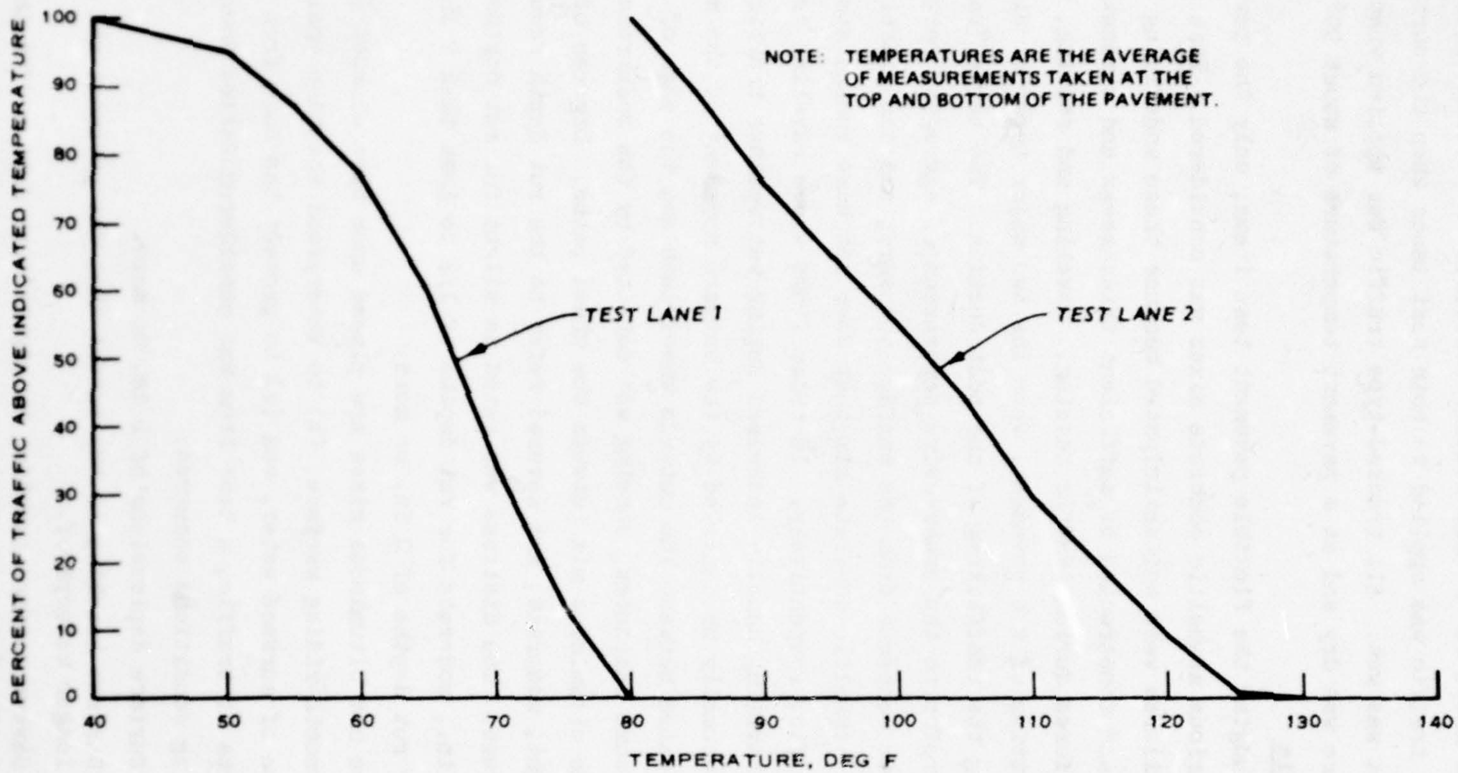


Figure 11. Traffic and pavement temperature - distribution curves for test lanes 1 and 2

temperature was above 80° F (hot weather traffic). A portion of the M51 dump truck traffic was applied to both test lanes when the surface of the pavement was wet. All tracked-type traffic was applied when the pavement surface was dry and at a pavement temperature of about 90° F.

Failure criteria

55. In judging the flexible pavement test items, only the performance of the various asphaltic concrete mixes was considered. Base course or subgrade failures were not anticipated because these underlying layers were designed and constructed of sufficient thicknesses and strengths to prevent failures during traffic testing. Raveling and shoving, which resulted in rutting of the pavement, were the two major types of distress observed during the trafficking of the test section. The terms "raveling" and "shoving" refer to the progressive separation of aggregate particles in the asphaltic concrete from the surface downward, and the plastic movement of an asphaltic concrete mix that does not have enough stability to support traffic, respectively. In those items where raveling occurred, the degree of raveling usually increased during wet weather traffic. Shoving could normally be detected by the outward movement of the mix in the area located between the outside wheel path and the edge of the pavement. In some instances, shoving was detected by the occurrence of upheaval of the bituminous mix between the wheel paths. Degrees of distress (slight, moderate, and severe) refer to the rut depth resulting from the distress. The distress was rated as slight for rut depths of less than 1/2 in., moderate for rut depths of 1/2 to less than 2 in., and severe for rut depths of 2 in. or more.

56. Since hot bituminous mixes are placed upon base courses (a) to provide a smooth riding surface, (b) to waterproof the base against the penetration of surface water, and (c) to protect the base from the raveling effects of traffic, a test item was considered failed when any of the following conditions occurred:

- a. Surface depressions of 2 in. or more.
- b. Surface cracking to the extent that the pavement was no longer waterproof.
- c. Severe surface raveling to significant depths (for these tests, 2 in. or greater).

d. Severe shoving (for these tests, resulting rut depths of 2 in. or more).

## Behavior of Pavement Under Traffic

### General

57. Observations of the behavior of the test items were recorded throughout the traffic test period. These observations were supplemented by photographs. Level readings were taken on the pavement prior to and at either failure of an item or at the end of traffic to show the permanent deformation of the pavement under traffic for the lane being observed. After a failure, a thorough investigation was made by excavating test trenches across the traffic lane to observe the various layers in the structure, along with CBR measurements and other pertinent tests in these layers. The data obtained during the traffic tests on the test section (see layout in Figure 2) are presented in the following paragraphs.

58. It should be noted that the traffic volumes referred to in the following paragraphs are called operations and that one operation is equivalent to one 18,000-lb, single-axle, dual-wheel load traveling the full length of the test item.

### Lane 1, M51 5-ton dump truck

59. Visual observations. Very little distress was observed on the pavement surface of item 1 during traffic testing. A general view of this item prior to traffic is shown in Photo 21. There was no evidence of raveling, cracking, or shoving of the asphaltic concrete in this item during the entire traffic period. Indications were that a very large amount of traffic would be required to produce a significant amount of distress in the pavement; therefore, traffic was discontinued after 34,143 operations. This item was rated in excellent condition at this time and was in the general condition shown in the right-hand portion of Photo 22.

60. An overall view of item 2 prior to traffic is shown in Photo 23. Distress of the pavement was first noticed at about

8162 operations. A close-up of this distress, shoving of the asphaltic concrete in the outside wheel path, is shown in Photo 24. As traffic was continued, a slight rut developed in the outside wheel path due to this shoving. Except for the continued development of this rut, very little change in the condition of the pavement occurred to the end of traffic. Traffic was stopped after 34,143 operations, and this item was rated as in good condition. The maximum rut depth measured after traffic was 3/8 in. Photo 25 depicts the general condition of item 2 after traffic.

61. A general view of item 3 and item 4 before traffic is shown in Photos 26 and 27, respectively. Both of these items performed very well during traffic testing. The only pavement distress observed during trafficking of these two items was the raveling of the fine aggregate plus the exposure of smooth and polished large aggregate on the surface. After 34,143 operations, traffic was discontinued, and both items were rated as in good condition. General views of these items after traffic are shown in Photos 28 and 29.

62. An overall view of item 5 prior to traffic is shown in Photo 30. Raveling that resulted in rutting in the wheel paths was the only type of distress observed during traffic testing. Slight surface raveling of the fine aggregate was first detected after 6 operations. This raveling progressed very slowly during dry weather traffic. After about 1,450 operations, a few pieces of the larger aggregate had become dislodged (Photo 31). Smooth and polished large aggregate was also noticeable at this time. As traffic was continued, there was very little change in the performance of the pavement until traffic was applied during a rain. During wet weather traffic, the rate of raveling increased, and a slurry of water and dislodged aggregate particles formed in the wheel paths. However, after it rained and after the water evaporated, the rate of raveling decreased and many of the dislodged fine particles appeared to be recompacted in the wheel paths. Photos 32 and 33 depict a general view and close-up, respectively, of item 5 after 21,288 operations. Approximately 1,000 of these 21,288 operations were applied to the pavement either when it was raining or

when the pavement was wet. Photo 33 shows a rut about 1/4 in. in depth that developed in the outside wheel path after 21,288 operations. About 75 percent of this rut developed during the wet weather traffic. Throughout the remainder of traffic, the rate of raveling would increase during wet weather traffic and decrease during dry weather traffic. Test traffic was stopped after 34,143 operations, and the item was rated in poor condition due to raveling and rutting caused by raveling. The maximum rut depth measured after traffic in the inside wheel path was about 1/4 in., as compared with about 1 in. in the outside wheel path. As pointed out previously, the majority of the raveling occurred during wet weather traffic. Approximately 22 percent of the traffic applied in this item was done so on wet pavement.

63. The general behavior of items 6 and 7 during traffic was quite similar to that described for item 5. However, raveling developed faster in item 7 than in item 6 and faster in item 6 than in item 5. The only difference between the bituminous mixes placed in the three items was the asphalt contents of the mixes. The asphalt contents of the mixes in items 5, 6, and 7 were 5.5, 5.2, and 4.3 percent, respectively. Photo 34 depicts item 6 before traffic, and Photo 35 shows item 7 prior to traffic. As traffic was applied, surface raveling developed quite rapidly in these two items; as was pointed out previously, the degree of raveling depended upon the asphalt content of the particular mix. This phenomenon can be seen by comparing Photos 36 and 31. After the same amount of traffic, 1,450 operations, more raveling had occurred in item 7 (Photo 36) than in item 5 (Photo 31). The degree of raveling in item 6 after 1,450 operations was not quite as bad as that in item 7 at the same traffic level. At this time, ruts in the outside wheel paths in items 6 and 7 were about 1/4 and 1/2 in. deep, respectively. As traffic was continued, the raveling and rutting of the bituminous mixes continued to progress, especially during wet weather traffic. By 14,323 operations (1,924 operations during wet weather), the rut in the outside wheel path in item 7 had increased in depth to 2 in. and the item was considered failed. Rutting in this item was due to severe raveling in the wheel paths of the test vehicle. Photo 37 shows a

general view of item 7 after 14,323 operations (failure), and Photo 38 is a close-up of the 2-in.-deep rut in the outside wheel path at this time. Rut depths of 1-3/8 in. were measured in the inside wheel path of item 7 after 14,323 operations. Measurements in item 6 after 14,323 operations showed that the rut in the outside wheel path had increased in depth to 1-3/8 in.; therefore, traffic was continued. After a total of 21,288 operations (3,108 during wet weather), traffic was discontinued in item 6, and the item was rated failed because of severe raveling and rutting. A general view of item 6 after failure is shown in Photo 39. Photo 40 depicts the 2-in.-deep rut in the outside wheel path of item 6 at the end of traffic. The maximum rut depth measured in the inside wheel path of item 6 after 21,288 operations was 1/2 in.

64. The behavior of items 8 and 9 during traffic was essentially the same. Slight shoving of the bituminous mixes or tire imprints were observed in both items when traffic was applied during the hottest portion of the traffic period or when the average pavement temperature was about 80° F. A close-up of the outside wheel path in item 9 after 1,450 operations indicating tire imprints is shown in Photo 41. Slight polishing of the large aggregate was also observed in both items at this time. Traffic was continued to 34,143 operations in both items, with little or no change in the condition of the pavements. Indications were that a large number of operations would be required to produce any appreciable distress; therefore, traffic was discontinued. Views of items 8 and 9 at the end of traffic are shown in Photos 42 and 43, respectively.

65. A general view of item 10 prior to the application of traffic is shown in Photo 44. The majority of the pavement distress occurred in this item during the first portion of the traffic period. During this time, the average pavement temperature was between 75° and 80° F. Slight bleeding of the bituminous mix and tire imprints were observed after about 8 operations. Shoving in the outside wheel path was also detected at this time. As traffic was continued, the shoving was more pronounced and ruts developed in both wheel paths. After 1,450 operations,

a 1/2-in.-deep rut was measured in the outside wheel path; after 8,162 operations, this rut had increased in depth to about 1 in. (Photo 45). Surface rippling of the bituminous mix at the outside edge of the pavement indicating shoving can also be detected in Photo 45. Due to cooler pavement temperatures (70° F or below), very little change in the condition of the pavement occurred as traffic was continued, except for the exposure of the smooth and polished aggregate. After 34,143 operations, traffic was stopped, and this item was considered to be in satisfactory condition. Measurements across the width of the traffic lane at the end of traffic showed rut depths of 1/4 and 1 in. in the inside and outside wheel paths, respectively. An overall view of item 10 after 34,143 operations is shown in Photo 46.

66. Items 11 and 12 performed very well during the entire traffic period. General views of these items before traffic are shown in Photos 47 and 48. Slight shoving was detected in both items at the beginning of traffic but seemed to stop after about 8,162 operations. After 8,162 operations, a shallow rut had formed in both test items. The maximum rut depth measured at this time was 1/4 in. in item 11 and 3/8 in. in item 12. Traffic was continued to 34,143 operations, with little or no change in the condition of the two pavements. Indications were that a large number of operations would be required to produce any appreciable distress; therefore, traffic was discontinued. Items 11 and 12 were rated in satisfactory condition at the end of traffic. Photos 49 and 50 show a general view after traffic of items 11 and 12, respectively.

67. Although the mix placed in item 13 was made of the same aggregate as were the mixes placed in items 5 through 7, item 13 performed much better during traffic. The only difference between the bituminous mixes was the asphalt content. The asphalt content of item 13 was 6.7 percent, as compared with 4.3 to 5.7 percent for items 5 through 7. As mentioned previously (paragraph 63), items 6 and 7 failed during traffic testing, and 1-in.-deep ruts were measured in item 5 after traffic. The maximum rut depth measured in item 13 after traffic was about 1/4 in. A general view of item 13 prior to traffic is shown

in Photo 51. As traffic was applied, slight raveling of the fines and exposure of the smooth surface of the larger aggregate were the only signs of distress observed in item 13. A close-up view depicting surface raveling after 1,450 operations is shown in Photo 52. After approximately 14,323 operations, ruts of about 1/8-in. depth due to raveling were measured in both wheel paths. By 34,143 operations (7,692 during wet weather), these ruts had increased in depth to about 1/4 in. Indications were that wet weather traffic had very little effect on the degree of raveling in this item and that a large number of operations would be required to produce a significant amount of distress in the pavement; therefore, traffic was discontinued at this time. Item 13 was rated in satisfactory condition at the end of traffic. An overall view of this item after 34,143 operations is shown in Photo 53.

68. Permanent pavement deformation. Level readings were taken across the test lanes at predetermined stations prior to and at failure or the end of traffic in each item. These observations were made to determine the magnitude of pavement deformation resulting from traffic. Typical cross sections for the 13 test items are shown in Figures 12-15. These data indicate that rutting occurred in the outside wheel path of all items and in the inside wheel path of all items except 1, 2, 3, and 9. These data also indicate that rutting was more pronounced in the outside wheel path.

69. Failure investigations. After failure in items 6 and 7 and after traffic in item 5, a test trench was excavated across the traffic lane to determine the extent of distortion of the various pavement elements. Views of these test pits are shown in Photos 54-56. In-place CBR, water content, and density determinations were also made of the different elements as these trenches were excavated. Results of these tests are presented in Table 11. A summary of thickness measurements of the bituminous pavement layers and the total thickness over the subgrade as measured in the test trenches is also shown in Table 11.

70. The test trenches did not reveal any distortion of the lime-stabilized base or of the subgrade in any of these test items. Therefore, rutting in all three items was attributed to raveling or the

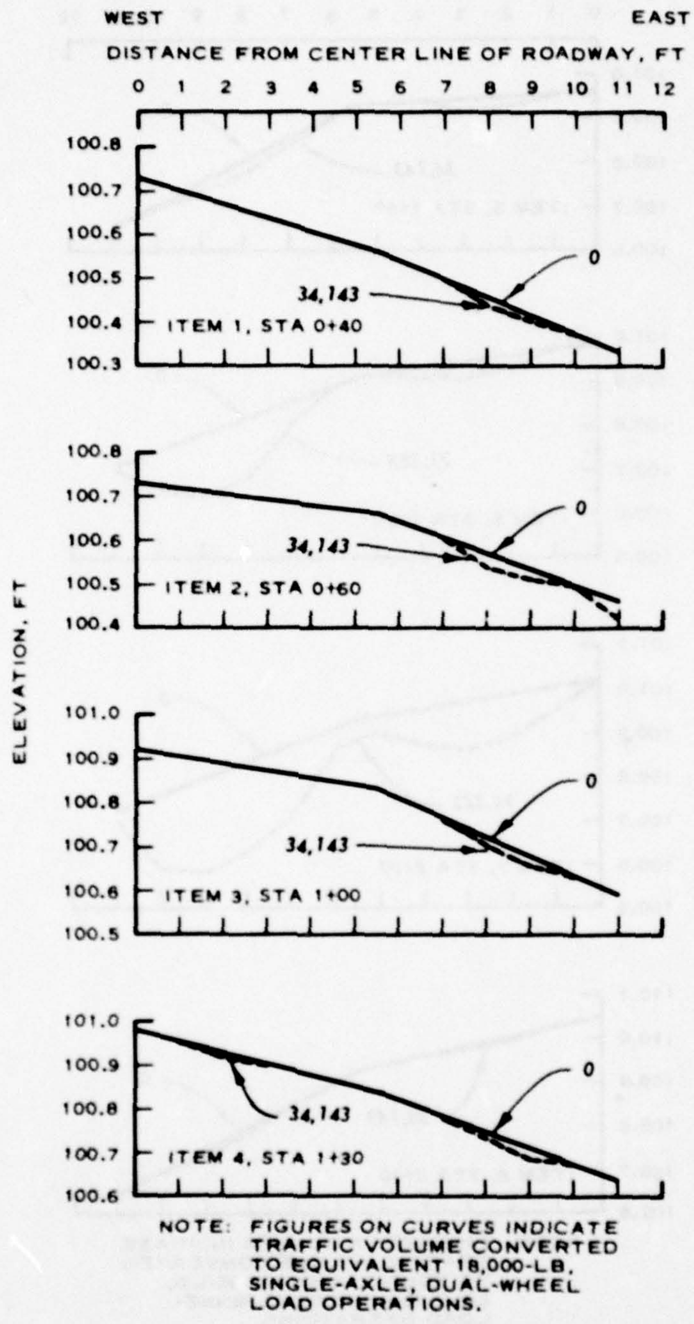


Figure 12. Typical cross sections of items 1-4, lane 1

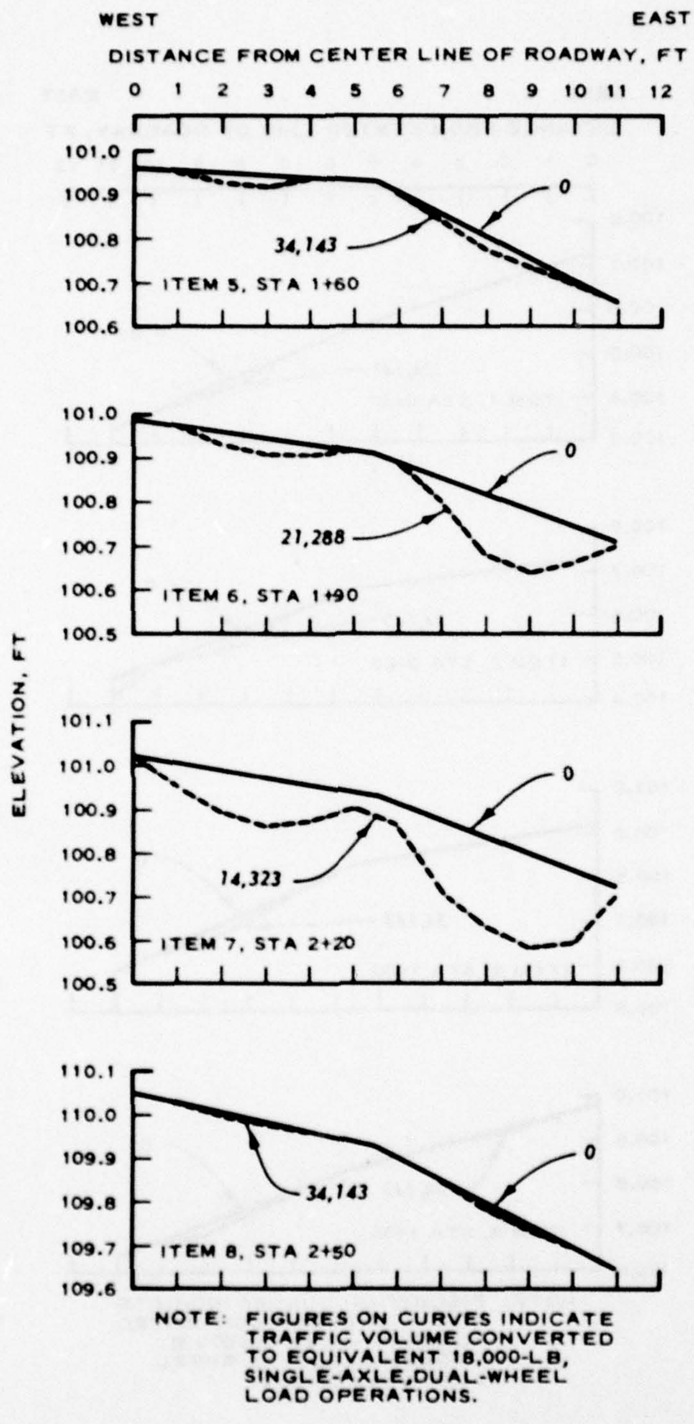


Figure 13. Typical cross sections of items 5-8, lane 1

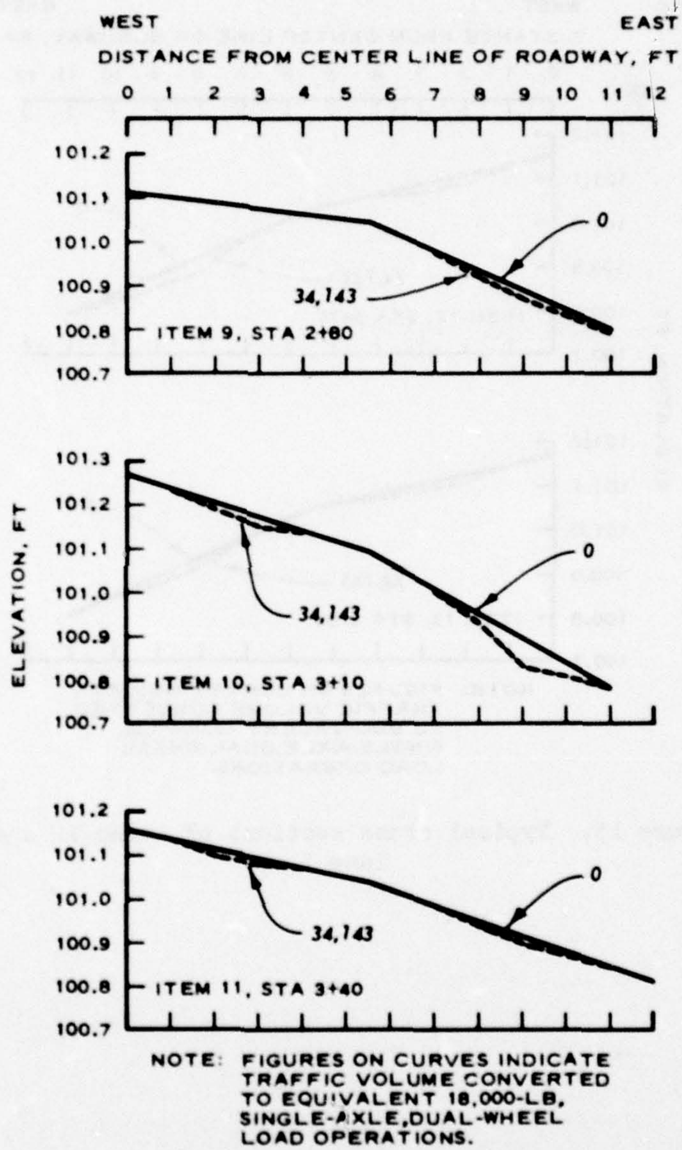


Figure 14. Typical cross sections of items 9-11, lane 1

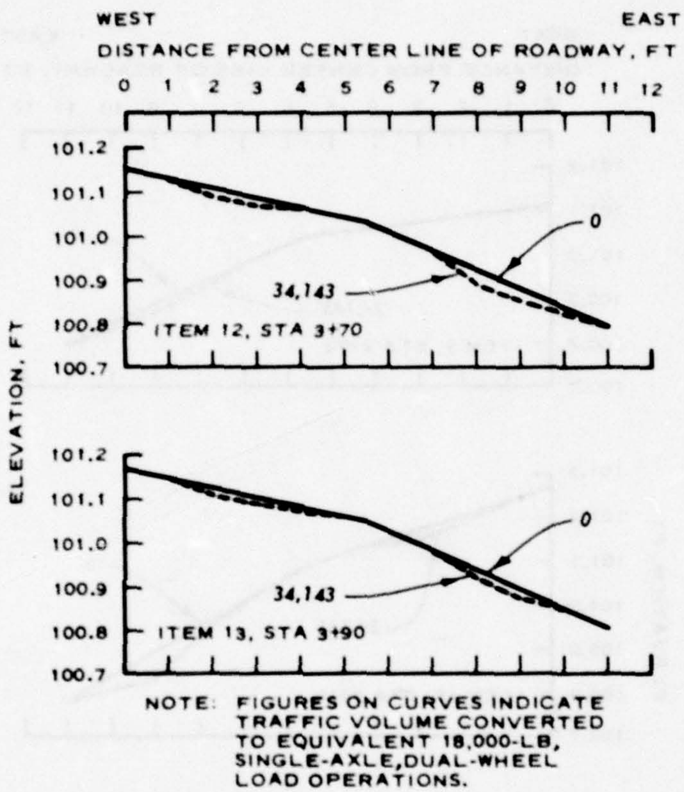


Figure 15. Typical cross sections of items 12 and 13, lane 1

disintegration of the bituminous mixes. Layer thickness measurements taken in and between the wheel paths also indicate raveling of the asphaltic concrete. In all instances, there was a thicker layer of asphaltic concrete between the wheel paths than there was within the wheel path of the test vehicle. The CBR, water content, and density data obtained from these pits are not significantly different from the as-constructed data shown in Table 7.

Lane 2, M51 5-ton dump truck

71. Visual observations. Items 1-4 behaved similarly and quite well during traffic testing. Test items 1, 2, 3, and 4 of lane 2, prior to traffic, are shown in Photos 21, 23, 26, and 27, respectively. The first distress observed in any of these items was tire imprints plus slight shoving in item 2 after about 576 operations. The average pavement temperature at this time was about 95° F. Very little additional shoving was observed in item 2 throughout the remainder of the traffic period even though 60,000 to 70,000 operations were applied at pavement temperatures ranging between 95° and 133° F. After approximately 44,400 operations, 1/8-in.-deep ruts were measured in all four items. Exposure of the smooth surface of the larger aggregate was also observed in items 2-4 at this time. General views of the first four items after 44,400 operations are shown in Photos 57-60. The loose aggregate shown on the surfaces of these items is partially the result of raveling in items 5-7. During traffic testing, the tires of the test vehicle tended to pick up loose aggregate from the maneuver areas and the raveled material in items 5-7 and deposit the material over the entire test section. Traffic was continued to 106,752 operations, and at this time it appeared that all four items would carry test traffic indefinitely. Therefore, traffic was discontinued. At the end of traffic, 1/4-in.-deep ruts due to consolidation of the various asphaltic concrete mixes were measured in both wheel paths of the four test items. Exposure of the smooth and polished surfaces of the large aggregate was also observed in items 2-4 after traffic. Item 1 was rated in excellent condition, and items 2-4 were rated in satisfactory condition at the end of traffic. Overall views of items 1, 2, 3, and 4 after 106,752 operations are shown in Photos 22, 25, 28, and 29, respectively.

72. Items 5, 6, and 7 behaved similarly during traffic testing. Raveling occurred in all items; however, the amount of raveling was a function of the asphalt content of the mix and type of weather during traffic application. As the asphalt content increased, the amount of raveling decreased; during wet weather traffic, the amount or rate of raveling increased in all three items. Overall views of items 5, 6, and 7 prior to traffic are shown in Photos 30, 34, and 35, respectively. Slight raveling of the surface fines was detected in each item early in the traffic period. After about 7,320 operations, 1/8-in.-deep ruts due to raveling were measured in item 7. At traffic levels of 9,720 and 44,400 operations, 1/8-in.-deep ruts due to raveling were measured in items 6 and 5, respectively. By 44,400 operations, the ruts in item 7 had increased in depth to about 1/2 in. The roughness of the surface texture in item 7 at this time was due to the raveling of the fine aggregate (Photo 61). The majority of the raveling in these items at this time occurred during three days of wet weather traffic. Approximately 11,600 operations were applied to the test section during these three days. Views of items 5, 6, and 7 after 44,400 operations are shown in Photos 62, 63, and 64, respectively. As traffic was continued, only minor raveling occurred in these items until the pavement became wet. After 106,752 operations, traffic was discontinued, and items 5 and 6 were rated in fair condition and item 7 in poor condition. Between 44,400 operations and the end of traffic, the ruts in items 5 and 6 increased in depth about 1/8 in., and those in item 7 increased in depth about 1/4 in. The majority of the raveling and rut progression in these items during this period occurred on the final day of traffic testing. This was the only period after 44,400 operations that traffic was applied during rainy weather. About 3,840 operations were applied to the test items on this final day of traffic. The maximum rut depths measured in items 5, 6, and 7 after 106,752 operations were 1/4, 3/8, and 3/4 in., respectively. Also at this time, the surface of item 7 was partially covered with raveled large aggregate, and the surface texture of items 5 and 6 was similar to that shown in Photo 61.

73. Shoving in the outside wheel path was detected throughout the

traffic period of items 8 and 9. General views of items 8 and 9 prior to traffic are shown in Photos 65 and 66, respectively. Rutting in the outside wheel paths, which resulted from shoving, was more severe in item 8. The only difference in the mixes placed in items 8 and 9 was the asphalt content. The asphalt contents of items 8 and 9 were 6.2 and 5.6 percent, respectively. Shoving was noticed in both items at the beginning of traffic; after 9,720 operations, 1/2- and 1/4-in. ruts due to shoving were detected in items 8 and 9, respectively. As traffic was continued, these ruts increased in depth. The only other distress observed in these items during traffic was tire imprints in item 8 at pavement temperatures of 120° F or higher plus upheaval of the mix in item 8 between the wheel paths. At the end of traffic, 106,752 operations, the ruts in the outside wheel paths of items 8 and 9 had increased in depth to about 1-1/2 and 3/4 in., respectively. Very little shoving or rutting developed in the inside wheel paths of these items during trafficking. The maximum upheaval in item 8 after traffic was about 3/8 in. Items 8 and 9 were rated in fair and good condition, respectively, at the end of traffic.

74. A general view of item 10 prior to traffic is shown in Photo 44. The mix placed in this item was very soft, and shoving was quite evident during traffic testing. At pavement temperatures of about 110° F or more, the mix would be soft enough that heel prints could be detected on the surface after walking across the item. Ruts due to shoving developed quite rapidly in the outside wheel path. After about 7,320 operations, a 1-1/8-in.-deep rut was measured in the outside wheel path. By 44,400 operations, this rut had increased in depth to about 1-1/2 in., and a 1/4-in. rut was measured in the inside wheel path. Shoving was much more noticeable in this item during hot weather traffic than during cold weather traffic. A comparison of the degree of shoving in lane 1, item 10, after 34,143 operations and lane 2, item 10, after 44,400 operations is shown in Photo 67. Lane 2 is in the foreground of this photograph. As detected in Photo 67, the paint line (vertical line) dividing items 10 and 11 had moved quite a bit in lane 2 and very little in lane 1. This photograph also shows

that very little shoving had occurred in the inside wheel path of lane 2 after 44,400 operations. Although traffic was applied in this item at higher pavement temperatures after 44,400 operations, very little additional shoving occurred for the remainder of the traffic period. After 106,752 operations, traffic was stopped, and item 10 was rated in poor condition. At this time, 1-7/8- and 3/8-in. ruts were measured in the outside and inside wheel paths, respectively, and the maximum upheaval between the wheel paths was about 3/8 in.

75. General views of items 11 and 12 prior to traffic are shown in Photos 47 and 48. There was very little difference between the performances of items 11 and 12 during traffic. Shoving and rutting developed in the outside wheel paths of both items in the early stages of traffic testing. After 7,320 operations, 7/8- and 1/2-in.-deep ruts due to shoving were measured in the outside wheel paths of items 11 and 12, respectively. The depths of these ruts gradually increased as traffic was continued due to movement of the bituminous mixes under the wheel loads of the test vehicle. After 106,752 operations, traffic was discontinued, and both items were rated in poor condition. At this time, the outside wheel path ruts had increased in depth to about 1-1/4 and 1 in. in items 11 and 12, respectively. The maximum rut depth measured in the inside wheel paths of these items after traffic was only about 1/4 in. The only other distress observed in items 11 and 12 was tire imprints at pavement temperatures of 120° F or more.

76. Slight raveling of the surface fines and exposure of the smooth and polished surfaces of the large aggregate were the only signs of distress observed in item 13 throughout traffic testing. The surface of this item became dusty due to dislodged fines in the early portion of the traffic period, and during wet weather traffic (approximately 15,500 operations), a slurry of these fines and water would form in both wheel paths. During the wet weather traffic, there was no noticeable increase in the rate of raveling as there was in the other items (5-7) with their mixes made of the same type of aggregate. Indications were that a very large amount of traffic would be required to produce a significant amount of distress in the pavement; therefore, traffic was discontinued after

106,752 operations. At this time, slight rutting (1/4 in. deep) due to raveling and polishing of the exposed larger aggregate was observed in both wheel paths. Item 13 was considered in good condition at the end of traffic.

77. Permanent pavement deformation. Level readings were taken, as described in paragraph 57, to determine the magnitude of rutting or upheaval developed in the traffic lane during traffic. Plots of typical cross-section measurements taken in items 1-13 are shown in Figures 16-19. These data indicate that the maximum rut deformation measured in these items after traffic was: 1/4 in. in items 1-5 and 13; 3/8 in. in item 6; 3/4 in. in items 7 and 9; and 1, 1-1/4, 1-1/2, and 1-7/8 in. in items 12, 11, 8, and 10, respectively. These data also indicate that maximum rutting occurred in the outside wheel path of the traffic lane. Upheavals of 3/8 in. were measured between the wheel paths in items 8 and 10.

Lane 3, M113 armored personnel carrier

78. Visual observations. One hundred-thirty operations (326 passes) were applied with the M113 to the test section at a pavement temperature of about 70° F. No raveling, shoving, or scuffing was detected after traffic; and indications were that a large number of operations would be required to produce distress; therefore, traffic was discontinued.

Lane 4, M48A1 tank

79. Visual observations. Twenty straight passes of the M48A1 tank (50,000 operations) showed very little effect on the flexible pavement test section. The M48A1 was operated in the center portion of the 22-ft-wide roadway at a pavement temperature of about 80° F. Only minor scuffing and slight raveling were observed in items 6 and 7. The tank was not operated on the flexible pavement section during wet weather.

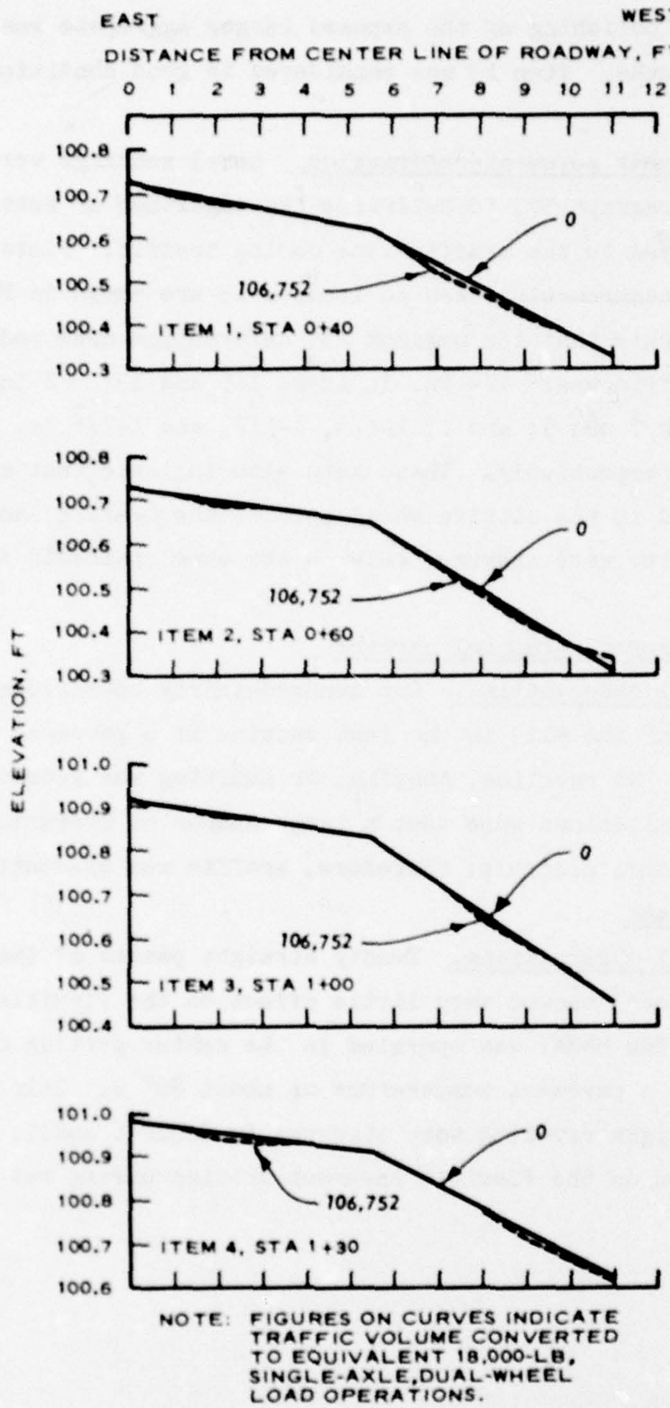


Figure 16. Typical cross sections of items 1-4, lane 2

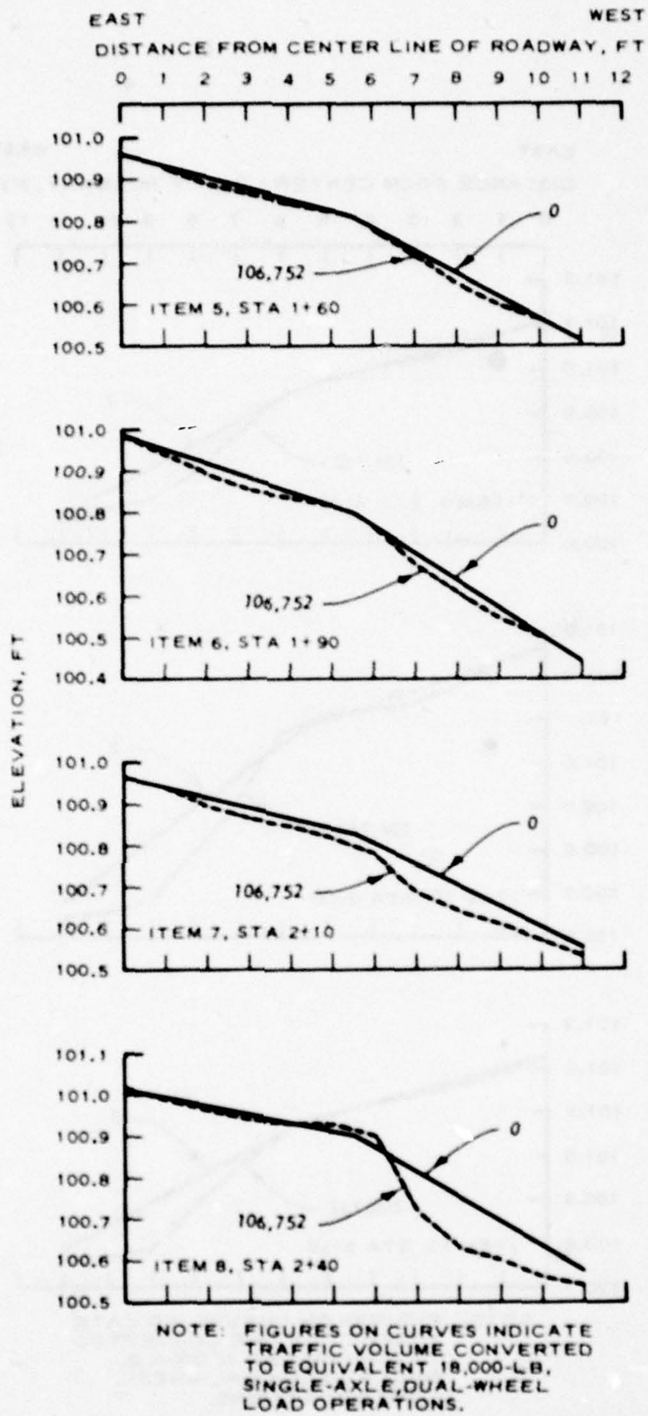


Figure 17. Typical cross sections of items 5-8, lane 2

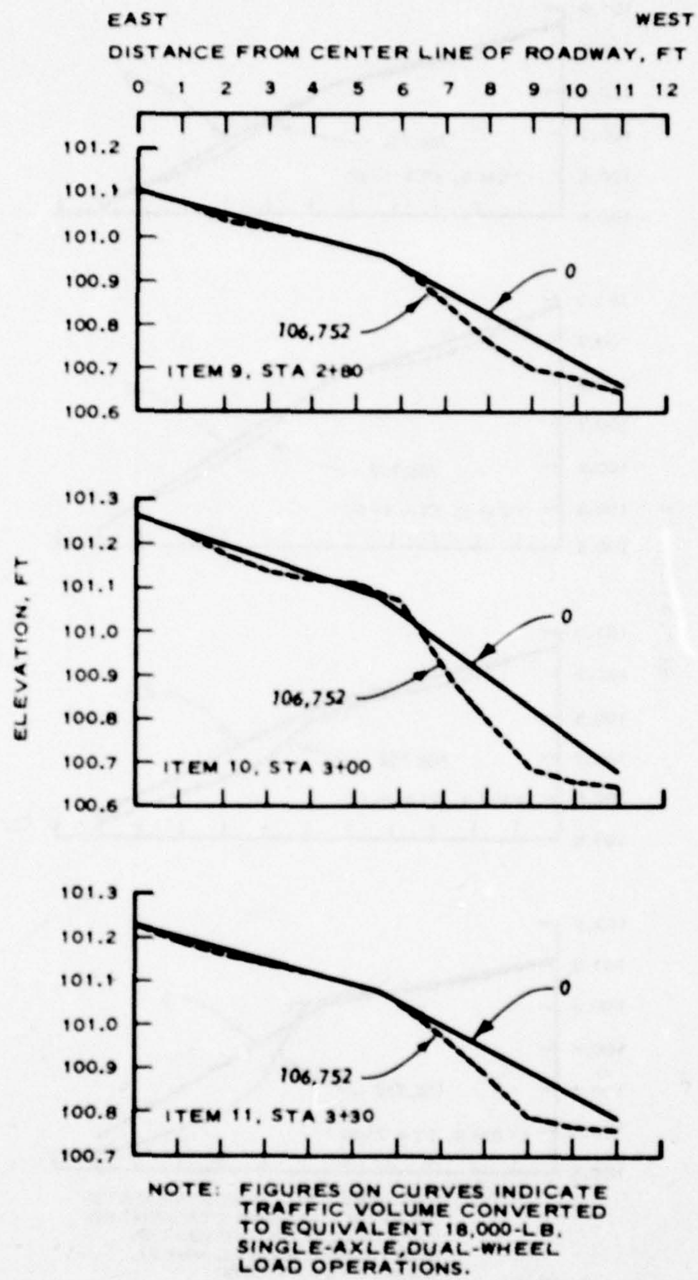


Figure 18. Typical cross sections of items 9-11, lane 2

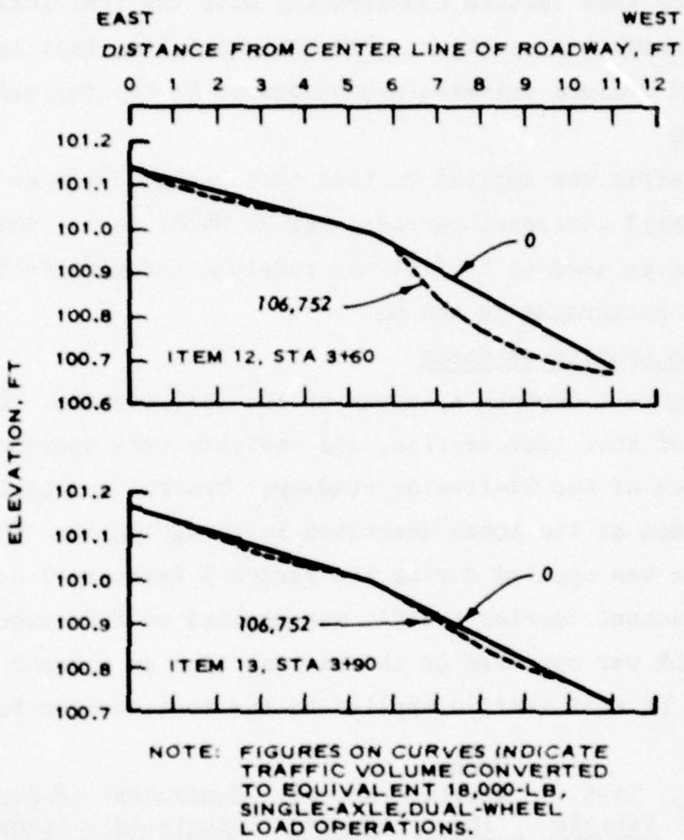


Figure 19. Typical cross sections of items 12 and 13, lane 2

## PART V: TESTING AND BEHAVIOR UNDER TRAFFIC - RIGID PAVEMENT

### Test Conditions and Procedures

#### General

80. Traffic tests were performed on one lane of the 22-ft-wide by 397-ft-long test section concurrently with the trafficking of the flexible pavement test section. The test vehicles, test lane, traffic patterns, and failure criteria are discussed in the following paragraphs.

#### Test vehicles

81. Traffic was applied to this test section with an M51 5-ton dump truck, M113 personnel carrier, and an M48A1 tank. These vehicles were the same as used to traffic the flexible pavement section and are discussed in paragraphs 50 and 51.

#### Test lane and traffic patterns

82. Figure 1 depicts a layout of the test section. During the trafficking of this test section, all vehicles were operated in the center portion of the 22-ft-wide roadway. Traffic was applied in the same manner and at the loads described in paragraph 53. The pneumatic-tired traffic was applied during the period 9 February-7 July 1977. The M113 personnel carrier traffic was applied on 8 December 1977, and the M48A1 tank was operated on the test section on 6 March 1978. The total amount of test traffic applied to the test section was as follows:

| Test Vehicle | Gross Weight lb | No. of Passes | Equivalent 18-kip Single-Axle Loads |
|---|---|---|---|
| M51 | 41,145 | 1,750 | 6,125 |
| M51 | 48,695 | 9,906 | 118,872 |
| M113 | 19,000 | 326 | 130 |
| M48A1 | 103,210 | 20 | 50,000 |

#### Failure criteria

83. The three failure conditions used for judging plain, nonreinforced rigid pavements were used in judging the performances of zero-slump mixes during trafficking. These failure conditions are as follows:

a. Initial-crack failure. A crack that is visible at the surface of the pavement, extends through the thickness of the slab, and is a result of traffic loading constitutes the initial-crack failure condition.

b. Shattered slab failure. Cracking that is visible on the pavement surface and subdivides a pavement slab into six pieces constitutes the shattered slab failure condition. In this investigation, a slab was considered the mix placed in one 11-ft-wide paving lane the entire length of an item. The cracking must be that associated with traffic loading rather than that resulting from some minor defect or early life cracking prior to the application of traffic.

c. Complete failure. Cracking that is visible on the pavement surface and subdivides the pavement slab into individual pieces having an area of less than about 15 sq ft each and that is characterized by severe raveling and/or pumping through cracks constitutes complete failure.

## Behavior of Pavement Under Traffic

### General

84. The behavior of the six test items (see layout in Figure 1) under traffic from various test vehicles as determined from the visual observations and measurements made during traffic is discussed in the following paragraphs.

### Lane 1, M51 5-ton dump truck

85. Visual observations. A general view of item 1 prior to traffic is shown in Photo 7. As can be seen, the general appearance of the surface was rough due to roller marks during compaction. No shrinkage cracks had developed in the pavement during the curing period. At the beginning of traffic, flaking along the ridges left by the roller was evident; however, after several passes of the test vehicle, very little progression of flaking was observed for the remainder of traffic. After 375 operations, raveling was detected in the east wheel path. This raveling began at the juncture of items 1 and 2 and extended into item 1 about 7 ft. Random cracking was noticed at the transition of items 1 and 2 after about 15,000 operations and at the opposite end of item 1 after about 73,000 operations. Since random cracking appeared only in transition areas, they were not considered in judging the performance

of this item. The only distress detected between sta 0+10 and 0+60, the center portion of item 1, during traffic was slight flaking along the ridges formed by the roller during construction. After 125,000 operations, traffic was stopped because indications were that a very large amount of traffic would be required to produce any type of significant distress. This item was considered to be in excellent condition at this time. An overall view of item 1 after traffic is shown in Photo 68.

86. An overall view of item 2 prior to traffic is shown in Photo 69. This item performed very poorly during traffic and was rated as failed after 18,245 operations. Transverse hairline cracks were detected in the west paving lane after 35 operations. Slight raveling was also observed in the east wheel path of this item at this time. As traffic continued, severe raveling caused ruts to develop in both wheel paths. Traffic was stopped after 18,245 operations, and the item was rated as failed. At this time, 3- to 4-in. ruts were measured in both wheel paths, and 1-1/2-in. upheaval was measured at the edges of these ruts. The upheaval and ruts were attributed to severe raveling. Pumping was also observed in both wheel paths at the end of traffic. An investigation trench was excavated and backfilled after 18,245 operations; then, the raveled material was fine-bladed with a motor grader, and traffic continued to 125,000 operations. A view of this item after 125,000 operations is shown in Photo 70. As noted in the upper portion of this figure, only a small area in the west paving lane of this item withstood 125,000 operations without distress. After reviewing the notes taken during construction, it was decided that the probable cause for the poor performance during trafficking of item 2 was a result of construction problems. Because of breakdowns of the concrete plant, most of the mix placed in this item was not compacted until several hours after placement. A light rain also occurred during some of the placement and all of the compaction of the mix placed in this item.

87. The only distress observed in item 3 before traffic was checking on the surface (Photo 71). The first distress due to traffic that was considered in the performance of the pavement placed in this item was noticed after about 88,409 operations. This distress was a transverse

hairline crack located at about sta 1+46 and extending from the joint of the two paving lanes about 4 ft towards the west edge of the pavement. Random hairline cracks were also noticed at both ends of this item at this time; however, these cracks were not considered in the evaluation of the mix placed in this item because they were in transition areas. Very little additional distress was detected as traffic was continued to 125,000 operations. At this time, the crack at sta 1+46 had extended to the west edge of the pavement and was between 1/8 and 1/4 in. wide at the surface due to minor spalling. A hairline crack was also detected at this time in the joint of the two paving lanes. This crack ran from the south end to about the center of the item. Traffic was discontinued after 125,000 operations, and the item was rated in excellent condition. A general view of item 3 after 125,000 operations is shown in Photo 72.

88. The performance of item 4 during traffic was quite similar to that of item 3. Photo 73 depicts an overall view of item 4 prior to traffic. One transverse shrinkage crack developed across the roadway during the curing period. The initial crack due to traffic occurred at the joint of the two paving lanes after 4,585 operations. Slight spalling of the transverse and longitudinal cracks was noticed after 18,821 operations. At this time, random cracking had developed at both ends of the item; however, the cracks in these transition areas were not considered in the evaluation of the pavement (see previous paragraph). After about 20,093 operations, the width of the longitudinal and transverse cracks was about 1/8 in. The only other crack, a transverse crack at sta 2+00, due to traffic, was detected after 25,565 operations. Minor spalling of the existing cracks was the only other distress observed throughout the remainder of the traffic period. After 125,000 operations, traffic was halted, and the test item was rated in excellent condition. At this time, the crack that developed during curing was about 1/2 in. wide at the surface caused by spalling. The depth of spalling was only about 1/4 in. The other two cracks were about 1/4 in. wide at the surface due to spalling. The general condition of the pavement after 125,000 operations is shown in Photo 74.

89. A general view of item 5 before traffic is shown in Photo 75. As soon as traffic was applied, surface raveling was evident in both wheel paths of the test vehicle. After 434 operations, slight rutting was noticed in the wheel paths as raveling progressed. Pumping was detected throughout the entire item during the first wet weather traffic or at about 3535 operations. As traffic continued, the raveling and associated ruts became more pronounced. Traffic was stopped after 5390 operations, and item 5 was considered failed because of severe raveling and rutting. The maximum depth of rut measured after traffic was about 4-1/2 in. (Photo 76). Upheaval of about 2-1/4 in. was also measured in the edges of the wheel paths when this item was rated as failed. The general condition of the pavement after 5390 operations (failure) is shown in Photo 77.

90. The condition of item 6 before the application of traffic is shown in Photo 78. Two transverse cracks extending across the width of the pavement were detected before traffic was commenced. Photo 79 is a closeup view of one of these cracks. The pavement in this item performed very well structurally during traffic testing. However, during wet weather traffic the surface became slippery. The first distress observed during traffic was several 2- to 3-ft-long hairline transverse cracks after 18,821 operations. No further cracks developed, and only slight spalling occurred during the remainder of traffic. Traffic was stopped after 125,000 operations because there were indications that a very large amount of traffic would be required to produce any significant distress. An overall view of item 6 at this time is shown in Photo 80. The performance of this item was rated good although the pavement performed excellently structurally during traffic. The good rating was assigned to this item because skid resistance decreased during wet weather.

91. Permanent pavement deformation. Level readings were taken in each item prior to traffic and at either failure or after traffic across the traffic lane at predetermined stations. The observations were made to determine the magnitude of pavement deformation resulting from traffic. Typical cross sections plotted for each item are shown in Figures 20 and 21.

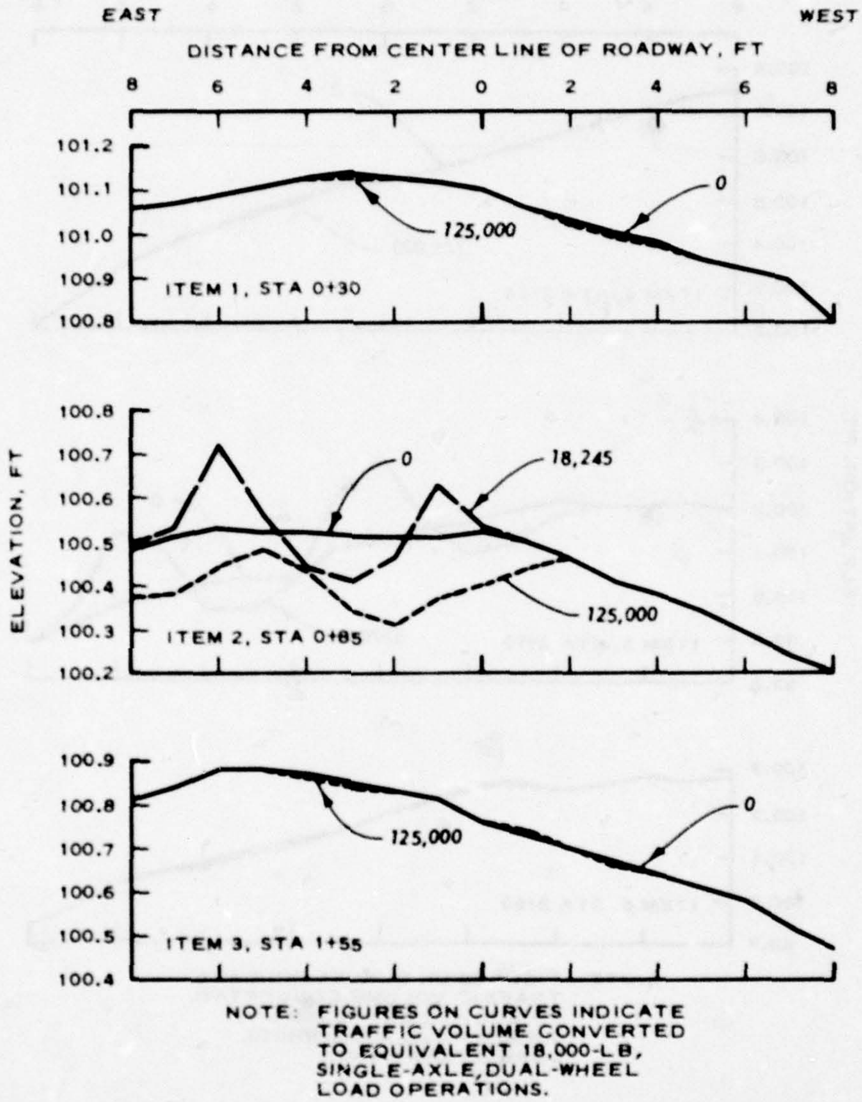


Figure 20. Typical cross sections of items 1-3, zero slump

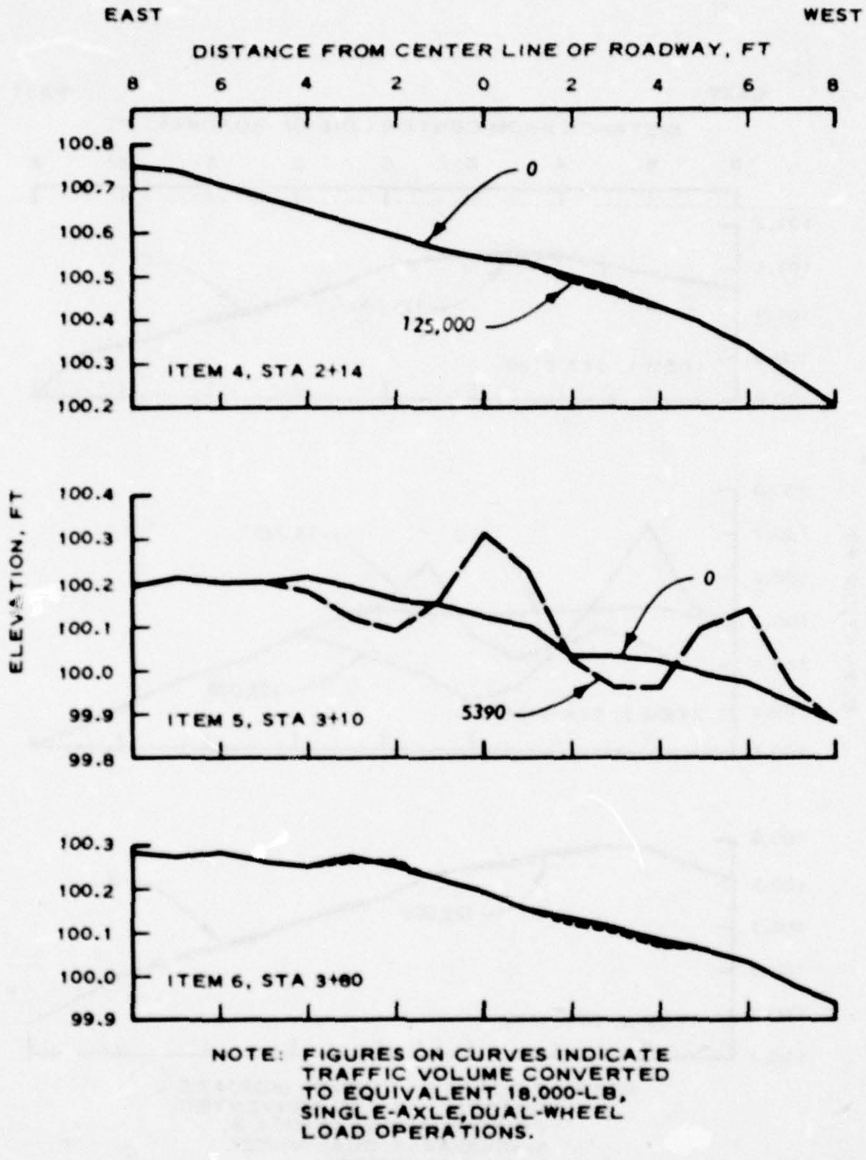


Figure 21. Typical cross sections of items 4-6, zero slump

92. Failure investigations. After failure in items 2 and 5, a test trench was excavated across the traffic lane to determine the extent of distortion of the various pavement elements. In-place CBR, water content, and density determinations were also made of the pavement elements as the test trenches were excavated. A summary of these test results is shown in Table 11. These test trenches did not reveal any distortion of the subgrade in either item; however, approximately 1/2-in. permanent deformation of the base material was detected in the wheel paths of item 5.

Lane 2, M113 armored personnel carrier

93. Approximately 130 operations were applied to the test section on 8 December 1977. No distress was detected during these 130 operations. Indications were that a large volume of traffic would be required to produce distress; therefore, traffic was discontinued.

Lane 3, M48A1 tank

94. Twenty straight passes of the M48A1 tank (50,000 operations) showed no adverse effects to items 1, 3, 4, and 6 of the rigid pavement test section. Since items 2 and 5 were considered failed prior to the tank traffic, the effects of traffic on these two items were not recorded.

## PART VI: DISCUSSIONS OF TEST RESULTS AND CONCLUSIONS

### Construction Procedures

#### Bituminous mixes

95. In general, the construction procedure using marginal materials for hot bituminous mix pavements is very similar to the procedure followed in constructing standard hot asphaltic-concrete mix pavements. After base course construction, the base is primed; the bituminous mix is made in a hot bituminous mixing plant; and then the mix is placed and compacted. During the mixing process, considerable care should be given to ensure that all aggregate material is uniformly coated with asphalt cement. Prior to making a mix from aggregate materials containing an appreciable amount of minus No. 200 sieve material, such as the gravelly-clayey sand used in the mixes placed in items 5-7 and 13, the material should be processed to ensure uniform mixing. Before central-plant mixing operations, this material was spread in thin layers (8 to 10 in. thick) and then pulvimixed and aerated until all of the clods were broken down to pass a 1-1/2-in. screen. Failure to process highly plastic materials in this manner prior to plant mixing will result in either a considerable amount of plant downtime because of being clogged with wet material or a nonuniform mix containing clay balls coated only on the outside with asphalt cement. To ensure a well-mixed bituminous material, all marginal materials should be processed until they can be fed to the mixing plant through a cold aggregate storage and feed unit without problems.

96. No problems occurred during placement of these marginal material mixes; however, the temperatures of the mixes placed in items 2-4 and 10-12 during compaction were important. Initial efforts to compact these mixes with a steel-wheel roller and a self-propelled rubber-tired roller at normal rolling temperatures of 250° F or above were unsuccessful due to the low stability of these mixes. However, after these mixes had cooled to 130°-190° F, they were successfully compacted. Compaction temperatures for all items are shown in Table 9.

## Zero-slump concrete mixes

97. The general construction procedure for marginal material zero-slump concrete pavements includes: (a) processing the material as required prior to mixing; (b) mixing the aggregate, cement, and water in a central mixing plant; (c) transporting the mix to the construction site by dump truck; (d) placing the mix by either motor grader or asphalt spreader; and (e) then compacting the mix with several passes of a heavy vibratory roller. As discussed in paragraph 95, high plastic materials should be processed to ensure uniform mixing. After mixing, the zero-slump mix was transported to the jobsite via dump truck without any problems.

98. Problems were encountered during placement of the mix; however, they can be eliminated by (a) increasing the volume of mix produced per hour, (b) paving larger areas, and (c) thoroughly cleaning the paving machine after each day's use. The average production rate obtained during placement of this mix was between 6 and 8 cu yd/hr. This small production rate resulted in cold joints and spreading problems, especially with the motor grader, because of limited working space. By the time enough mix had been end dumped on the base for spreading with the motor grader, the mix that was first dumped had begun to set up, and the short length (70 ft) of the test item allowed very little operating room for the motor grader. The only other problem that occurred during placement was with the asphalt finisher. The screed on the finisher was not cleaned underneath, and the buildup of concrete on the underside of the screed tended to weight the screed down. During the placement of the mix in item 6, only about a 2-in.-thick layer of mix could be placed in one pass due to the extra weight on the screed caused by concrete buildup and to the low stability of the mix. It is believed that these problems could be eliminated during actual pavement construction by (a) employing one single or several small mixers capable of producing from 50 to 75 cu yd/hr, (b) paving areas that are at least 200-300 ft in length, and (c) properly cleaning the equipment after each day's work.

99. No problems were encountered while compacting the marginal material mixes with the heavy vibratory roller. The surface obtained

after compaction of the motor-grader- and asphalt-spreader-placed mix was satisfactory for secondary roads, streets, base courses, and parking areas. Although the Bomag 220A roller was the only compactor used to compact the mix placed for this study, other rollers have been tested at the WES and will satisfactorily compact zero-slump portland cement concrete.[1]

## Traffic Results - Flexible

100. Test results indicate that the bituminous mixes made with the gravelly-sand (SP) aggregate (items 2-4) performed as well structurally under pneumatic-tired traffic as did the bituminous mix made with high-quality crushed stone (item 1). However, during the traffic period exposure of the smooth and polished surfaces of some of the larger aggregate was observed in items 2-4. Test items (6 and 7), which consisted of lean bituminous mixes with asphalt contents of 5.2 and 4.3 percent, respectively, made with gravelly-clayey sand, performed unsatisfactorily because of raveling. The rate of raveling in these items increased considerably during wet weather traffic. Test items 5 and 13 constructed with this same aggregate at asphalt contents of 5.5 and 6.7 percent, respectively, performed much better with less raveling and rutting. These items performed satisfactorily for the entire traffic period. The rut depth values listed in the summary of traffic test data (Table 12) indicate substantial rutting developed in items 8-12 during hot weather traffic. However, as can be determined from the cross-section plots shown in Figures 16-19, rutting was more pronounced in the outside wheel paths of these items than it was in the inside wheel paths. The outside wheel path was near the edge of pavement, and the rutting was primarily caused by internal shoving, which could be eliminated by lateral containment of the mix (paving the shoulders). Although the aggregate gradation of the mixes placed in items 8 and 9 was the same and the aggregate gradation of the mixes placed in items 11 and 12 was the same, rutting was more severe in items 8 and 11 during traffic than it was in items 9 and 12. It is believed that the larger ruts that

occurred in items 8 and 11 were partially caused by the higher asphalt content of the mixes placed in these items. The asphalt content of the mix placed in item 8 was 6.2 percent as compared with 5.6 percent for the mix placed in item 9 and the asphalt contents of the mixes placed in items 11 and 12 were 7.4 and 5.9 percent, respectively. A slight amount of the rutting that occurred in items 2-13 is also attributed to consolidation of the mix under traffic. This can be determined by comparing column 10 with columns 4 and 13 in Table 9. The densities of the bituminous mixes within the wheel paths after traffic (column 10) were greater than the densities of the respective mixes either prior to traffic (column 4) or after traffic and between the wheel paths (column 13).

101. All 13 test items withstood the straight-pass-type traffic applied with the M113 and M48A1 tracked vehicles without any noticeable distress.

## Traffic Results - Rigid

102. Test results indicate that the zero-slump concrete mixes made of pit run gravelly sand, poorly graded sand, and gravelly-clayey sand performed very well during traffic. The mixes made from these materials were placed in items 3, 4, and 6. Only slight minor cracking was observed in any of these items after traffic. However, it should be noted that the surface of item 6 tended to become slippery during wet weather traffic. Item 6 contained the mix made from the highly plastic gravelly-clayey sand.

103. The mix made with the open-graded gravel (G3) and placed in item 5 failed because of severe raveling. Only 5,390 operations were applied to this item before failure as compared with about 125,000 operations applied to items 3, 4, and 6 without a failure.

104. The standard zero-slump mix placed in item 2 failed after 18,245 operations. However, as explained previously, it is believed that the poor behavior of this mix was caused by construction problems.

105. Although the placement procedures resulted in the surface of item 1 being slightly rougher than the surface of items 2-6, the riding

quality of item 1 was satisfactory for truck traffic. The surface of item 1 was rougher because the mix in this item was placed by a motor grader under adverse conditions as compared with placement by an asphalt finisher in all other items. A summary of the pneumatic-tired traffic test data is shown in Table 13.

106. After the M51 5-ton dump truck traffic, a track-type vehicle traffic was applied to the test section. There was no distress observed in items 1, 3, 4, and 6 after 130 operations (326 passes) of an M113 personnel carrier and 50,000 operations (20 passes) of an M48A1 tank. Since items 2 and 5 were considered failed prior to track-type traffic, the performance of these items during traffic was not considered.

## Analysis

107. It should be noted, as stated in paragraph 20, that the flexible pavement test section was designed and constructed to test the marginal material mixes as a wearing surface. Therefore, all of the mixes were placed on a strong base, which eliminated base or subgrade failure during traffic testing.

108. A summary of the traffic test results (rutting) and selected laboratory test results performed on the marginal materials and bituminous mixes made of these marginal materials is shown in Table 14. The uniformity coefficients ($C_u$) and coefficients of curvature ($C_c$) listed in columns 2 and 3 are the coefficients determined from an average gradation of the aggregate or the marginal material used in the bituminous mix that was placed in the test items indicated (column 1). The stabilities and retained stabilities listed in columns 5 and 6 are average results of laboratory tests performed on the bituminous mixes placed in the respective test items. The rut depths presented in columns 7 and 8 are the maximum measurements recorded either after traffic or at failure in the items indicated. Indications from these data shown in Table 14 combined with the visual observations made during traffic testing are that a satisfactory bituminous pavement can be made from almost any coarse-grained aggregate material. However, those

materials with a high (20 or greater) uniformity coefficient, or highly plastic materials require a high asphalt content (6.5 percent or greater), and those materials with a low uniformity coefficient and low coefficients of curvature require some type of containment system, such as paved shoulders, to prevent lateral movement of the outside edge of the traffic area. The results of the design methods for determining optimum asphalt content for marginal material mixes reported herein indicate that the Marshall design method is satisfactory for all materials except sands containing little or no fines. The surface area design method should be used for the sandy-type materials.

109. A summary of pertinent laboratory data performed on the zero-slump mixes, marginal materials used in these mixes, and the rating of the test items after pneumatic-tired traffic is shown in Table 15. As can be determined from the data presented in this table, only the sand-aggregate ratio of the mix (column 3) seemed to have an effect on the performance of the mixture during traffic. As discussed previously, the poor performance of mixture 1 placed in item 2 was attributed to construction problems. Indications from the data shown in Table 15 plus the visual observations made during traffic testing are that a satisfactory zero-slump concrete mix can be made from an aggregate material if:

- a. The sand-aggregate ratio is 25 or greater.
- b. The flexural strength of the mixture after 28 days is 125 psi or greater.

## Conclusions

110. Based on the results of the tests presented herein, the following conclusions are believed warranted:

- a. The concept of utilizing marginal materials in making hot bituminous asphaltic concrete mix and zero-slump portland cement concrete is applicable for pavements that are to be used as secondary roads, streets, parking lots, storage areas, or for relatively short service life pavements.

b. Asphaltic concrete can be made from a wide range (almost any material with 100 percent passing the 1-1/2-in. sieve to about 15 percent passing the No. 200 sieve) of coarse-grained soils.

c. The Marshall design procedure can be used for designing all marginal material hot bituminous mixes, except those made with sands containing little or no fines. The surface area method should be used to design hot bituminous mixes made with sands.

d. If laboratory test facilities are not available, the asphalt content of hot bituminous mixes made with marginal aggregate materials should range between about 5.5 and 6.5 percent.

e. The stability of a bituminous mix made from a marginal material should be 300 lb or greater, and the retained stability of this mix should be at least 50 percent.

f. Bituminous mixes made of highly plastic aggregate materials can be expected to ravel, especially during wet weather traffic.

g. Highly plastic aggregate materials that are to be used in a hot bituminous mix or a zero-slump concrete mix should be thoroughly processed prior to incorporating asphalt cement or portland cement to ensure a uniform mixture.

h. The sand-aggregate ratio of a marginal material to be used in a zero-slump concrete mixture should be 25 or more.

i. Satisfactory placement of zero-slump concrete can be accomplished with a conventional base course spreader, asphalt finisher, or motor patrol.

j. Zero-slump concrete can be adequately compacted with heavy vibratory rollers.

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Table 1

Aggregate Test Properties

| Description | Percent Passing | | | | |
|---|---|---|---|---|---|
| | 100% Clayey Sand (S1) | 100% Concrete Sand (S2) | 100% Masonry Sand (S3) | 100% Clayey-Gravelly Sand (G1) | 100% Nonplastic Gravelly Sand (G2) |
| Gradation Sieve Size | | | | | |
| 1-1/2 in. | 100 | 100 | 100 | 100 | 100 |
| 1 in. | 100 | 100 | 100 | 86 | 98 |
| 3/4 in. | 100 | 100 | 100 | 78 | 89 |
| 1/2 in. | 100 | 100 | 100 | 72 | 86 |
| 3/8 in. | 100 | 100 | 100 | 67 | 82 |
| No. 4 | 100 | 97 | 100 | 61 | 77 |
| No. 8 | 100 | 88 | 100 | 57 | 74 |
| No. 16 | 100 | 82 | 99 | 55 | 72 |
| No. 30 | 100 | 67 | 85 | 52 | 65 |
| No. 50 | 92 | 14 | 10 | 30 | 12 |
| No. 100 | 53 | 3 | 2 | 17 | 5 |
| No. 200 | 32 | 1 | 1 | 15 | 4.5 |
| Specific gravity | 2.67 | 2.65 | 2.65 | 2.66 | 2.64 |
| Absorption | 1.4 | 0.8 | 0.2 | 2.1 | 1.4 |
| Sand equivalency | 32 | 91 | 88 | 20 | 34 |
| Plasticity index | 9 | N.P. | N.P. | 15 | N.P. |

Table 2

Asphalt Properties

| Property | Test Result |
|---|---|
| Penetration, 0.1 millimetres | 91 |
| Viscosity, c st 140°F | 1779 |
| Ductility, cm | 150+ |
| Specific gravity | 1.035 |
| Solubility, percent | 99.7 |
| Flash point, deg F | 570 |

Table 3

Mix Properties at Optimum Asphalt Content

| Mix | Optimum Asphalt Content Percent by Weight | Optimum Asphalt Content Percent by Volume | Sand Equivalent | Percent Passing No. 200 Sieve | Percent Voids in Mineral Aggregate | Percent Voids Total Mix | Percent Voids Filled With Asphalt | Stability lb | Retained Stability percent | Flow 0.01 in. | Density pcf | Indirect Tensile Strength psi | Shear Strength at 60 psi Normal Pressure psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100% G1 | 7.8 | 17.0 | 20 | 15 | 21.7 | 4.8 | 78.2 | 882 | 20 | 14 | 140.7 | 94 | 202 |
| 100% G2 | 10.6 | 22.2 | 34 | 4 | 26.6 | 4.4 | 83.6 | 398 | 60 | 16 | 135.2 | 26 | 116 |
| 100% S1 | 12.7 | 25.5 | 32 | 32 | 32.0 | 6.6 | 79.5 | 871 | 94 | 15 | 129.6 | 55 | 138 |
| 100% S2 | 10.3 | 21.4 | 91 | 1 | 27.0 | 5.6 | 79.2 | 185 | 106 | 13 | 134.4 | 29 | 73 |
| 100% S3 | 11.8 | 23.7 | 88 | 1 | 30.8 | 7.2 | 76.8 | 106 | 134 | 14 | 129.6 | 19 | 66 |
| 90% G1-10% S1 | 8.1 | 17.6 | 20 | 17 | 22.1 | 4.5 | 79.6 | 1160 | 20 | 14 | 140.6 | 84 | 199 |
| 80% G1-20% S1 | 8.6 | 18.7 | 22 | 18 | 22.8 | 4.2 | 81.7 | 1329 | 31 | 12 | 140.2 | 80 | 177 |
| 70% G1-30% S1 | 9.1 | 19.8 | 23 | 21 | 24.0 | 4.4 | 81.5 | 1410 | 56 | 16 | 136.8 | 78 | 158 |
| 50% G1-50% S1 | 10.2 | 21.5 | 30 | 24 | 26.5 | 5.0 | 81.2 | 1326 | 59 | 16 | 136.1 | 108 | 179 |
| 25% G1-75% S1 | 11.4 | 23.4 | 31 | 28 | 29.5 | 6.1 | 79.2 | 905 | 87 | 11 | 132.4 | 56 | 149 |
| 90% G1-10% S2 | 8.0 | 17.4 | 19 | 14 | 22.4 | 5.0 | 77.6 | 852 | 27 | 16 | 139.9 | 69 | 176 |
| 80% G1-20% S2 | 8.1 | 17.6 | 19 | 12 | 22.1 | 4.4 | 79.6 | 1074 | 30 | 16 | 140.4 | 81 | 181 |
| 70% G1-30% S2 | 8.4 | 18.3 | 21 | 11 | 22.4 | 4.1 | 81.6 | 859 | 30 | 14 | 140.4 | 85 | 181 |
| 25% G1-75% S2 | 9.6 | 20.4 | 60 | 5 | 25.0 | 4.6 | 81.7 | 330 | 93 | 14 | 137.4 | 37 | 118 |
| 90% G1-10% S3 | 8.2 | 17.8 | 20 | 14 | 22.1 | 4.4 | 80.4 | 1075 | 23 | 15 | 140.4 | 73 | 169 |
| 80% G1-20% S3 | 8.6 | 18.7 | 21 | 12 | 22.6 | 4.0 | 82.4 | 958 | 42 | 14 | 140.2 | 68 | 166 |
| 70% G1-30% S3 | 8.8 | 19.0 | 23 | 11 | 23.4 | 4.4 | 81.2 | 862 | 57 | 14 | 139.2 | 66 | 154 |
| 50% G1-50% S3 | 9.5 | 20.1 | 32 | 8 | 25.2 | 5.2 | 79.6 | 399 | 67 | 12 | 136.8 | 35 | 96 |
| 25% G1-75% S3 | 10.7 | 22.2 | 60 | 4 | 27.8 | 5.6 | 79.7 | 184 | 116 | 14 | 133.9 | 34 | 94 |

(Continued)

Table 3 (Concluded)

| Mix | Optimum Asphalt Content Percent by Weight | Optimum Asphalt Content Percent by Volume | Sand Equivalent | Percent Passing No. 200 Sieve | Percent Voids in Mineral Aggregate | Percent Voids Total Mix | Percent Voids Filled With Asphalt | Stability lb | Retained Stability percent | Flow 0.01 in. | Density pcf | Indirect Tensile Strength psi | Shear Strength at 60 psi Normal Pressure psi |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90% G2-10% S1 | 10.2 | 21.7 | 34 | 7 | 25.3 | 3.6 | 85.8 | 670. | 49 | 13 | 137.2 | 53 | 160 |
| 80% G2-20% S1 | 9.7 | 20.6 | 34 | 10 | 24.9 | 4.3 | 82.8 | 672 | 79 | 13 | 137.2 | 47 | 156 |
| 70% G2-30% S1 | 9.9 | 21.1 | 34 | 13 | 24.8 | 3.8 | 85.0 | 872 | 66 | 12 | 137.8 | 51 | 198 |
| 50% G2-50% S1 | 10.4 | 21.9 | 28 | 18 | 26.4 | 4.6 | 82.8 | 985 | 75 | 12 | 136.0 | 61 | 153 |
| 25% G2-75% S1 | 11.5 | 23.6 | 29 | 25 | 29.4 | 5.8 | 80.2 | 870 | 86 | 11 | 132.4 | 57 | 150 |
| 90% G2-10% S2 | 10.6 | 22.2 | 37 | 4 | 26.7 | 4.6 | 83.0 | 335 | 56 | 13 | 135.0 | 43 | 114 |
| 80% G2-20% S2 | 10.6 | 22.2 | 40 | 4 | 26.7 | 4.6 | 83.0 | 447 | 47 | 13 | 135.1 | 28 | 130 |
| 70% G2-30% S2 | 10.6 | 22.2 | 45 | 4 | 26.7 | 4.5 | 83.2 | 384 | 53 | 14 | 135.2 | 31 | 130 |
| 50% G2-50% S2 | 10.5 | 22.0 | 57 | 3 | 26.6 | 4.7 | 82.4 | 309 | 86 | 14 | 135.2 | 26 | 129 |
| 25% G2-75% S2 | 10.4 | 21.6 | 73 | 2 | 27.3 | 5.6 | 79.2 | 199 | 100 | 12 | 134.2 | 23 | 106 |
| 90% G2-10% S3 | 10.9 | 22.8 | 37 | 4 | 27.0 | 4.2 | 84.6 | 399 | 64 | 14 | 135.0 | 24 | 125 |
| 80% G2-20% S3 | 10.9 | 22.7 | 40 | 4 | 27.3 | 4.6 | 83.4 | 431 | 52 | 16 | 134.5 | 27 | 103 |
| 70% G2-30% S3 | 11.4 | 23.6 | 47 | 3 | 28.2 | 4.6 | 83.6 | 224 | 91 | 18 | 133.6 | 24 | 82 |
| 50% G2-50% S3 | 11.7 | 23.9 | 62 | 3 | 29.5 | 5.6 | 80.9 | 155 | 91 | 19 | 131.7 | 18 | 79 |
| 25% G2-75% S3 | 11.9 | 24.0 | 75 | 2 | 30.4 | 6.4 | 78.9 | 112 | 85 | 20 | 130.4 | 17 | 78 |
| Crushed gravel | 9.5 | 20.6 | 89 | 4 | 24.0 | 3.4 | 85.6 | 1642 | 92 | 12 | 139.8 | 61 | 170 |
| Crushed limestone | 5.7 | 13.3 | 86 | 4 | 16.4 | 3.2 | 80.8 | 1404 | 118 | 12 | 150.4 | 69 | 195 |

Table 4

Selected Asphalt Contents for Marginal Material Test Road

| Material | Test Item | Optimum Asphalt Content Percent by Marshall Mix Design | Asphalt Content Percent by Surface Area Method 6 microns + Absorption | Asphalt Content Used in Test Item |
|---|---|---|---|---|
| Crushed limestone (GW), 1 | 1 | 5.7 | 5.5 | 5.8 |
| Gravelly Sand (SP), G2 | 2<br>3<br>4 | 7.5 | 5.0 | 7.6<br>6.7<br>5.4 |
| Gravelly-Clayey Sand (SC), G1 | 5<br>6<br>7<br>13 | 9.0 | 8.7 | 5.5<br>5.2<br>4.3<br>6.7 |
| 80 percent G2<br>20 percent S1 | 8<br>9 | 6.2 | 7.0 | 6.2<br>5.6 |
| Concrete Sand (SP), S2 | 10 | 9.8 | 5.2 | 6.4 |
| 75 percent S2<br>25 percent S1 | 11<br>12 | 7.8 | 7.4 | 7.4<br>5.9 |

Table 5

Properties of Zero-Slump Concrete Mixtures

| Mixture No. | Test Item | Cement lb/cu yd | W/C Ratio | S/A Ratio | Aggregate(s) |
|---|---|---|---|---|---|
| 1 | 1, 2 | 517 | 0.32 | 0.32 | S1, G3 |
| 2 | 3 | 517 | 0.37 | 0.53 | G2* |
| 3 | 4 | 517 | 0.67 | 1.00 | S2 |
| 4 | 5 | 517 | 0.25 | 0.0 | G3 |
| 5 | 6 | 517 | 0.57 | 0.67 | G1** |

* Pit run material

** Clay gravel.

Table 6

Flexural Strength Test Data
Specimens Fabricated in the Laboratory

| Mixture No. | Beam No. | Wet Sand Cured 7 Days | Fog Room Cured 7 Days | Wet Sand Cured 28 Days | Fog Room Cured 28 Days |
|---|---|---|---|---|---|
| 1 | 1 | 830 | -- | -- | -- |
| | 2 | -- | -- | 1065 | -- |
| | 3 | -- | 750 | -- | -- |
| | 4 | -- | -- | -- | 925 |
| 2 | 9 | 665 | -- | -- | -- |
| | 10 | -- | -- | 790 | -- |
| | 11 | -- | 660 | -- | -- |
| | 12 | -- | -- | -- | 750 |
| 3 | 13 | 220 | -- | -- | -- |
| | 14 | -- | -- | 340 | -- |
| | 15 | -- | 250 | -- | -- |
| | 16 | -- | -- | -- | 425 |
| 4 | 17 | 215 | -- | -- | -- |
| | 18 | -- | -- | 310 | -- |
| | 19 | -- | 210 | -- | -- |
| | 20 | -- | -- | -- | 300 |
| 5 | 21 | 205 | -- | -- | -- |
| | 22 | -- | -- | 240 | -- |
| | 23 | -- | 205 | -- | -- |
| | 24 | -- | -- | -- | 260 |

Table 7

As-Constructed Moisture, Density, and Strength Data for Marginal Materials Test Sections

| Test Item | Station | Material | Design Thickness in. | Depth in. | CBR | Modulus of Soil Reaction, k pci | Water Content percent | Dry Density, pcf In-Place A | Dry Density, pcf CE 55** B | Percent CE 55 Density A/B |
|---|---|---|---|---|---|---|---|---|---|---|
| **Flexible Pavement Test Section** | | | | | | | | | | |
| 3 | 1+00 | Lime-stabilized base (SC) | 6 | 0 | 150+ | -- | 6.8 | 134.4 | 131.5 | 102 |
| | | Subgrade (CL) | -- | 6 | 18 | -- | 15.9 | 94.2 | 110.8 | 85 |
| | | | | 12 | 29 | -- | 13.8 | 114.3 | 115.2 | 99 |
| | | | | 18 | 20 | -- | 19.8 | 101.2 | 104.4 | 97 |
| 10 | 3+00 | Lime-stabilized base (SC) | 6 | 0 | 150+ | -- | 5.2 | 135.8 | 128.5 | 106 |
| | | Subgrade (CL) | -- | 6 | 16 | -- | 19.3 | 91.9 | 105.2 | 87 |
| | | | | 12 | 28 | -- | 13.1 | 107.2 | 114.8 | 93 |
| | | | | 18 | 23 | -- | 14.8 | 112.0 | 115.1 | 97 |
| Maneuver area | 4+50 | Lime-stabilized base (SC) | 6 | 0 | 150+ | -- | 5.7 | 135.2 | 129.7 | 104 |
| | | Subgrade (CL) | -- | 6 | 18 | -- | 18.8 | 93.1 | 106.5 | 87 |
| | | | | 12 | 26 | -- | 17.5 | 97.1 | 109.5 | 89 |
| | | | | 18 | 28 | -- | 15.4 | 107.9 | 114.2 | 95 |
| **Zero-Slump Concrete Test Section** | | | | | | | | | | |
| 2 | 1+00 | Base | 4* | 0 | -- | 714 | -- | -- | -- | -- |
| 5 | 2+75 | Base | 4* | 0 | -- | 435 | -- | -- | -- | -- |

* Existing thickness.

** Based on CE 55 maximum density at field-in-place water content.

Table 8

Bituminous Mix Properties of Plant-Mixed, Laboratory-Compacted Samples

| | | Laboratory-Compacted Samples** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aggregate Gradation Percent Passing | | | | | | | | | | | | | |
| Test Item | Material* | 1 in. | 3/4 in. | 1/2 in. | 3/8 in. | No. 4 | No. 16 | No. 50 | No. 200 | Asphalt Content percent | Stability lb | Flow 1/100 in. | Total Mix | Filled/AC | Unit Wt Total Mix pcf |
| 1 | Crushed limestone (GW) | 100 | 100.0 | 99.7 | 93.7 | 77.2 | 42.0 | 14.8 | 5.4 | 5.8 | 1484 | 14 | 8.5 | 60.0 | 142.3 |
| 2 | 100 percent G2 | 100 | 91.8 | 84.3 | 78.6 | 66.0 | 53.2 | 4.3 | 0.9 | 7.6 | 270 | 12 | 5.5 | 75.0 | 139.7 |
| 3 | 100 percent G2 | 100 | 95.8 | 86.0 | 81.1 | 69.8 | 56.3 | 4.1 | 1.0 | 6.7 | 162 | 7 | 7.7 | 65.0 | 138.2 |
| 4 | 100 percent G2 | 100 | 96.6 | 76.6 | 62.8 | 52.8 | 42.6 | 4.3 | 1.0 | 5.4 | 149 | 9 | 7.4 | 61.5 | 141.2 |
| 5 | 100 percent G1 | 100 | 92.0 | 86.8 | 81.9 | 74.9 | 65.4 | 22.9 | 12.1 | 5.5 | 715 | 16 | 13.1 | 45.9 | 130.2 |
| 6 | 100 percent G1 | 100 | 87.4 | 76.0 | 70.8 | 62.7 | 53.7 | 19.1 | 8.2 | 5.2 | 669 | 15 | 10.9 | 50.4 | 134.4 |
| 7 | 100 percent G1 | 100 | 98.7 | 90.0 | 86.9 | 79.2 | 69.2 | 25.4 | 12.4 | 4.3 | 706 | 16 | 17.3 | 32.7 | 126.0 |
| 8 | 80 percent G2-20 percent S1 | 100 | 91.9 | 81.8 | 78.5 | 68.0 | 55.5 | 7.6 | 3.0 | 6.2 | 285 | 8 | 7.0 | 65.8 | 140.3 |
| 9 | 80 percent G2-20 percent S1 | 100 | 90.0 | 82 2 | 77.4 | 69.4 | 57.6 | 13.9 | 6.0 | 5.6 | 677 | 9 | 7.6 | 61.8 | 140.7 |
| 10 | 100 percent S2 | 100 | 100.0 | 100.0 | 99.6 | 95.4 | 79.1 | 7.8 | 1.0 | 6.4 | 72 | 16 | 13.4 | 49.1 | 130.0 |
| 11 | 75 percent S2-25 percent S1 | 100 | 100.0 | 100.0 | 100.0 | 95.9 | 80.0 | 13.4 | 4.8 | 7.4 | 201 | 10 | 9.7 | 61.2 | 133.8 |
| 12 | 75 percent S2-25 percent S1 | 100 | 100.0 | 100.0 | 100.0 | 95.4 | 79.4 | 11.6 | 3.6 | 5.9 | 140 | 6 | 13.7 | 46.7 | 130.8 |
| 13 | 100 percent G1 | 100 | 93.2 | 85.6 | 80.6 | 73.3 | 64.8 | 25.6 | 13.3 | 6.7 | 690 | 14 | 9.9 | 58.1 | 132.7 |

* G1 - Gravelly-clayey sand (SC), PI = 24; G2 - Gravelly sand (SP); S1 - Clayey sand (SC), PI = 9; S2 - Poorly graded sand (SP).
** Specimens compacted by gyratory compaction, 100-psi pressure, 1-deg pitch, and 30 revolutions.

Table 9

Summary of Mat Temperatures at Compaction and Asphalt Content and Density Data of Field Cores

| | | Lane 1 Prior to Traffic September 1976 | | | Lane 2 Prior to Traffic May 1977 | | | Lane 1 After Traffic (34,143 Operations), June 1977 Inside Wheel Path | | | Lane 1 After Traffic (34,143 Operations), June 1977 Between Wheel Paths | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test Item | Mat Temperature at Compaction °F | Asphalt Content percent | Unit Wt Total Mix pcf | Percent Plant Laboratory Density | Asphalt Content percent | Unit Wt Total Mix pcf | Percent Plant Laboratory Density | Asphalt Content percent | Unit Wt Total Mix pcf | Percent Plant Laboratory Density | Asphalt Content percent | Unit Wt Total Mix pcf | Percent Plant Laboratory Density |
| 1 | 250 | 5.8 | 145.8 | 102.5 | 5.4 | 150.8 | 106.0 | 5.6 | 149.8 | 105.3 | -- | 151.0 | 106.1 |
| 2 | 180 | 7.2 | 138.1 | 98.9 | 5.5 | 140.4 | 100.5 | 6.5 | 141.3 | 101.1 | -- | 139.2 | 99.6 |
| 3 | 180 | 6.9 | 134.7 | 97.5 | 4.4 | 138.4 | 100.1 | 6.2 | 139.9 | 101.2 | -- | 138.9 | 100.5 |
| 4 | 180 | 5.7 | 135.2 | 95.8 | 4.1 | 138.9 | 98.4 | 5.3 | 138.4 | 98.0 | -- | 135.4 | 95.9 |
| 5 | 240 | 5.7 | 122.7 | 94.2 | 4.5 | 128.3 | 98.5 | 4.9 | 131.9 | 101.3 | -- | 128.5 | 98.7 |
| 6 | 240 | 4.6 | 120.2 | 89.4 | 4.5 | 123.4 | 91.8 | 5.4* | 131.2* | 97.6 | -- | 127.8 | 95.1 |
| 7 | 240 | 4.1 | 117.8 | 93.5 | 4.0 | 126.6 | 100.5 | 3.6** | 133.7** | 106.1 | -- | 125.9 | 99.9 |
| 8 | 200 | 6.7 | 134.4 | 95.8 | 5.3 | 140.0 | 99.8 | 5.6 | 141.6 | 100.9 | -- | 139.1 | 99.1 |
| 9 | 200 | 5.2 | 134.0 | 95.2 | 4.7 | 141.7 | 100.7 | 5.0 | 140.2 | 99.6 | -- | 137.9 | 98.0 |
| 10 | 130 | 6.3 | 125.9 | 96.8 | 7.2 | 128.0 | 98.5 | 6.1 | 126.1 | 97.0 | -- | 124.2 | 95.5 |
| 11 | 170 | 7.0 | 127.8 | 95.5 | 7.2 | 129.1 | 96.5 | 6.5 | 128.7 | 96.2 | -- | 126.1 | 94.2 |
| 12 | 190 | 6.3 | 127.8 | 97.7 | 5.8 | 122.8 | 93.9 | 6.0 | 130.1 | 99.5 | -- | 126.8 | 96.9 |
| 13 | 195 | 6.7 | 125.4 | 94.5 | 6.2 | 127.8 | 96.3 | 6.2 | 132.6 | 99.9 | -- | 129.3 | 97.4 |

* Cores taken after 21,288 operations.

** Cores taken after 14,323 operations.

Table 10

After-Traffic Water Content, Density, and CBR Data for Zero-Slump Concrete Test Section, Lane 1

| Test Item | Station | Location | Material | Depth in. | Layer Thickness in. | Total Thickness in. Design | Total Thickness in. Actual | Equivalent 18-kip S-Axle Loads | CBR | Water Content percent | Dry Density pcf |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0+90 | In wheel | Zero-slump | 0 | 2.5 | 10 | 6.5 | 18,245 | -- | -- | -- |
| | | path | Base (SC) | 2.5 | 4.0 | | | | 33 | 5.6 | 116.6 |
| | | | Subgrade (CL) | 6.5 | | | | | 79 | 13.9 | 107.6 |
| | | | (CL) | 12.5 | | | | | 44 | 14.2 | 112.2 |
| | | | (CL) | 18.5 | | | | | 39 | 14.8 | 110.3 |
| | | Between | Zero-slump | 0 | 4.0 | 10 | 8.0 | | -- | -- | -- |
| | | wheel | Base (SC) | 4.0 | 4.0 | | | | 36 | 5.1 | 118.8 |
| | | paths | Subgrade (CL) | 8.0 | | | | | 51 | 13.8 | 111.2 |
| | | | (CL) | 14.0 | | | | | 45 | 14.3 | 111.5 |
| | | | (CL) | 20.0 | | | | | 43 | 14.5 | 110.8 |
| 5 | 3+18 | In wheel | Zero-slump | 0 | 2.0 | 10 | 5.5 | 5,390 | -- | -- | -- |
| | | path | Base (SC) | 2.0 | 3.5 | | | | 37 | 5.9 | 111.9 |
| | | | Subgrade (CL) | 5.5 | | | | | 71 | 15.8 | 108.8 |
| | | | (CL) | 11.5 | | | | | 42 | 16.0 | 107.7 |
| | | | (CL) | 17.5 | | | | | 38 | 17.3 | 103.9 |
| | | Between | Zero-slump | 0 | 3.5 | 10 | 7.5 | | -- | -- | -- |
| | | wheel | Base (SC) | 3.5 | 4.0 | | | | 67 | 4.7 | 117.9 |
| | | paths | Subgrade (CL) | 7.5 | | | | | 62 | 14.9 | 111.0 |
| | | | (CL) | 13.5 | | | | | 59 | 14.9 | 110.6 |
| | | | (CL) | 19.5 | | | | | 45 | 16.0 | 108.0 |

Table 11

After-Traffic Water Content, Density, and CBR Data for Flexible Pavement Test Section, Lane 1

| Test Item | Station | Location | Material | Layer Depth in. | Layer Thickness in. | Total Thickness, in. Design | Total Thickness, in. Actual | Equivalent 18-Kip S-Axle Loads | CBR | Water Content percent | Dry Density, pcf In-Place A * |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1+50 | In wheel | Asphaltic concrete | 0 | 3.0 | 9 | 10.0 | 34,143 | -- | -- | -- |
| | | path | Stabilized base (SC) | 3.0 | 7.0 | | | | 150+ | 11.4 | 125.7 |
| | | | Subgrade (CL) | 10.0 | | | | | 13 | 20.2 | 101.2 |
| | | | (CL) | 16.0 | | | | | 30 | 14.2 | 111.5 |
| | | | (CL) | 22.0 | | | | | 41 | 14.7 | 108.4 |
| | | Between | Asphaltic concrete | 0 | 3.5 | 9 | 10.5 | | -- | -- | -- |
| | | wheel | Stabilized base (SC) | 3.5 | 7.0 | | | | 150+ | 11.6 | 123.7 |
| | | paths | Subgrade (CL) | 10.5 | | | | | 11 | 16.4 | 103.8 |
| | | | (CL) | 16.5 | | | | | 23 | 14.7 | 108.7 |
| | | | (CL) | 22.5 | | | | | 28 | 14.5 | 108.6 |
| 6 | 1+80 | In wheel | Asphaltic concrete | 0 | 0.4 | 9 | 4.9 | 21,288* | -- | -- | -- |
| | | paths | Stabilized base (SC) | 0.4 | 4.5 | | | | 106 | 11.8 | 123.3 |
| | | | Subgrade (CL) | 4.9 | | | | | 6 | 18.0 | 108.3 |
| | | | (CL) | 10.9 | | | | | 13 | 14.3 | 107.0 |
| | | | (CL) | 16.9 | | | | | 13 | 15.1 | 109.2 |
| | | Between | Asphaltic concrete | 0 | 2.8 | 9 | 10.8 | | -- | -- | -- |
| | | wheel | Stabilized base (SC) | 2.8 | 8.0 | | | | 112 | 11.9 | 123.7 |
| | | paths | Subgrade (CL) | 10.8 | | | | | 5 | 18.2 | 102.2 |
| | | | (CL) | 16.8 | | | | | 28 | 14.2 | 111.0 |
| | | | (CL) | 22.8 | | | | | 26 | 10.2 | 116.0 |
| 7 | 2+20 | In wheel | Asphaltic concrete | 0 | 0.8 | 9 | 7.8 | 14,323* | -- | -- | -- |
| | | path | Stabilized base (SC) | 0.8 | 7.0 | | | | 150+ | 11.7 | 124.6 |
| | | | Subgrade (CL) | 7.8 | | | | | 7 | 16.3 | 102.7 |
| | | | (CL) | 13.8 | | | | | 20 | 15.7 | 106.4 |
| | | | (CL) | 19.8 | | | | | 27 | 15.2 | 108.8 |
| | | Between | Asphaltic concrete | 0 | 2.0 | 9 | 9.5 | | -- | -- | -- |
| | | wheel | Stabilized base (SC) | 2.0 | 7.5 | | | | 150+ | 12.3 | 124.1 |
| | | paths | Subgrade (CL) | 9.5 | | | | | 7 | 21.6 | 101.3 |
| | | | (CL) | 15.5 | | | | | 30 | 14.9 | 108.8 |
| | | | (CL) | 21.5 | | | | | 15 | 15.3 | 106.7 |

Table 12

Summary of Traffic Test Data on Flexible Pavement, Lanes 1 and 2

| Test Item | Rut Depth at Indicated Traffic Level, in. | | | | | Degree of Raveling at Indicated Traffic Levels | | | | | Degree of Shoving at Indicated Traffic Levels | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1,450 | 5,162 | 14,323 | 21,288 | 36,143 | 1,450 | 5,162 | 14,323 | 21,288 | 36,143 | 1,450 | 5,162 | 14,323 | 21,288 | 36,143 | |
| | | | | | | | | | | Lane 1 | | | | | | |
| 1 | | | | 1/8 | 1/4 | | | | | | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete |
| 2 | | | 1/8 | 1/4 | 3/8 | | | | | | | | Slight | Slight | Slight | 3/8-in. rut due to shoving in outside wheel path |
| 3 | | | | | 1/4 | | | | | Slight | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete<br>Slight raveling of fine aggregate and polishing of large aggregate during traffic |
| 4 | | | | | 1/4 | | | | | Slight | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete<br>Slight raveling of fine aggregate and polishing of large aggregate during traffic |
| 5 | | | 1/16 | 1/4 | 1 | | | Slight | Slight | Moderate | | | | | | Approximately 1 in. of mix had raveled off in the wheel paths during traffic testing |
| 6 | 1/4 | 3/4 | 1-3/8 | 2 | | Slight | Moderate | Moderate | Severe | | | | | | | Failure @ 21,288 due to severe raveling and 2-in. rut |
| 7 | 1/2 | 1-1/4 | 2 | | | Moderate | Moderate | Severe | | | | | | | | Failure @ 14,323 due to severe raveling and 2-in. rut |
| 8 | | | | | 1/4 | | | | | | | | | | Slight | 1/4-in. rut due to consolidation and shoving of asphaltic concrete |
| 9 | | | | | 1/4 | | | | | | | | | | Slight | 1/4-in. rut due to consolidation and shoving of asphaltic concrete |
| 10 | 1/2 | 1 | 1 | 1 | 1 | | | | | | Moderate | Moderate | Moderate | Moderate | Moderate | 1-in. rut in outside wheel path due to shoving |
| 11 | 1/8 | 1/4 | 1/4 | 1/4 | 1/4 | | | | | | | | | | Slight | 1/4-in. rut due to consolidation and shoving of asphaltic concrete |
| 12 | 1/8 | 3/8 | 3/8 | 3/8 | 3/8 | | | | | | | | | Slight | Slight | 3/8-in. rut due to consolidation and shoving of asphaltic concrete |
| 13 | | | 1/8 | 1/8 | 1/4 | | | | | Slight | | | | | | 1/4-in. rut due to consolidation and slight raveling of asphaltic concrete |

(Continued)

Table 12 (Concluded)

| Test Item | Rut Depth at Indicated Traffic Level, in. 1,120 | 2,720 | 44,400 | 106,752 | Degree of Raveling at Indicated Traffic Level 1,120 | 2,720 | 44,400 | 106,752 | Degree of Shoving at Indicated Traffic Level 1,120 | 2,720 | 44,400 | 106,752 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Lane 2 | | | | |
| 1 | | | 1/8 | 1/4 | | | | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete |
| 2 | | | 1/8 | 1/4 | | | | | Slight | Slight | Slight | Slight | 1/4-in. rut due to consolidation and shoving of asphaltic concrete |
| | | | | | | | | | | | | | Tire imprints were observed at pavement temperature of 95°F |
| 3 | | | 1/8 | 1/4 | | | | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete |
| 4 | | | 1/8 | 1/4 | | | | | | | | | 1/4-in. rut due to consolidation of asphaltic concrete |
| 5 | | | 1/8 | 1/4 | | | | Slight | | | | | 1/4-in. rut due to raveling |
| | | | | | | | | | | | | | The majority of the raveling occurred during wet weather traffic |
| 6 | | 1/8 | 1/4 | 3/8 | | Slight | Slight | Slight | | | | | 3/8-in. rut due to raveling |
| | | | | | | | | | | | | | The majority of the raveling occurred during wet weather traffic |
| 7 | 1/8 | 1/4 | 1/2 | 3/4 | | Slight | Moderate | Moderate | | | | | 3/4-in. rut due to raveling of asphaltic concrete |
| | | | | | | | | | | | | | The majority of the raveling occurred during wet weather traffic |
| 8 | 1/2 | 1/2 | 3/4 | 1-1/2 | | | | | Slight | Moderate | Moderate | Moderate | Rutting due to shoving and upheaval of the asphaltic concrete |
| | | | | | | | | | | | | | Tire imprints were observed at pavement temperature of 120°F |
| 9 | 1/4 | 1/4 | 3/8 | 3/4 | | | | | | Slight | Slight | Moderate | Rutting due to shoving of the asphaltic concrete |
| 10 | 1-1/8 | 1-1/4 | 1-1/2 | 1-7/8 | | | | | Moderate | Moderate | Moderate | Moderate | Rutting due to shoving and upheaval of the asphaltic concrete |
| | | | | | | | | | | | | | Tire imprints were observed at pavement temperature of 120°F |
| 11 | 7/8 | 7/8 | 1 | 1-1/4 | | | | | Moderate | Moderate | Moderate | Moderate | Rutting due to shoving in outside wheel path |
| | | | | | | | | | | | | | Tire imprints were observed at pavement temperature of 120°F |
| 12 | 1/2 | 7/8 | 7/8 | 1 | | | | | Moderate | Moderate | Moderate | Moderate | Same as item 11 |
| 13 | | | 1/8 | 1/4 | | | | | | | Slight | Slight | Slight rutting during wet weather traffic |

Table 13

Summary of Traffic Test Data on Rigid Pavement

| Item | First Distress Type (Traffic Volume) | Failure Type (Traffic Volume) | Rating and Remarks |
|---|---|---|---|
| 1 | Flaking (875) | | Excellent - surface slightly rougher than in items 2-6 because of placement method (motor grader) |
| 2 | Transverse hairline cracks (35) | Severe raveling and rutting (18, 245) | Failed - failure due to construction problems |
| 3 | Transverse hairline crack (88, 409) | | Excellent - only hairline cracks after traffic |
| 4 | Shrinkage crack (0) | | Excellent - slight spalling of the two transverse and one longitudinal cracks after traffic |
| 5 | Raveling (875) | Severe raveling and rutting (5,390) | Failed - failure due to voids in mix |
| 6 | Shrinkage crack (0) | | Good - performed very well structurally during traffic; however, surface was slick during wet weather traffic |

Table 14

Summary of Flexible Pavement Test Data

| Test Items | Aggregate Coefficients | | | Mix Properties | | Performance Data Maximum Rut Depth, in. | |
|---|---|---|---|---|---|---|---|
| | $C_u$ | $C_c$ | $C_u/C_c$ | Stability lb | Retained Stability percent | Outside Wheel Path | Inside Wheel Path |
| 1 | 19.2 | 1.5 | 12.7 | 1,404 | 118 | 0.2 | 0.2 |
| 2-4 | 6.8 | 0.5 | 13.6 | 394 | 60 | 0.4 | 0.2 |
| 5-7, 13 | 24.0 | 4.2 | 5.7 | 882 | 20 | 2.0 | 1.3 |
| 8, 9 | 5.3 | 0.5 | 10.6 | 870 | 90 | 1.5 | 0.2 |
| 10 | 2.7 | 1.1 | 2.5 | 185 | 106 | 1.9 | 0.4 |
| 11, 12 | 3.6 | 1.4 | 2.6 | 300 | 100 | 1.3 | 0.2 |

Table 15

Summary of Rigid Pavement Test Data

| Test Item | Mixture No. | Mixture Properties: S/A Ratio | Mixture Properties: 28-Day Field Flexural Strength psi | Aggregate Coefficients: $C_u$ | Aggregate Coefficients: $C_c$ | Aggregate Coefficients: $C_u/C_c$ | Rating |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.32 | 750 | -- | -- | -- | Excellent |
| 2 | 1 | 0.32 | 750 | -- | -- | -- | Failed |
| 3 | 2 | 0.53 | 685 | 34.0 | 0.1 | 425.0 | Excellent |
| 4 | 3 | 1.00 | 590 | 2.8 | 1.3 | 2.2 | Excellent |
| 5 | 4 | 0.0 | 350 | 2.3 | 1.8 | 1.3 | Failed |
| 6 | 5 | 0.67 | 125 | 24.0 | 4.2 | 5.7 | Good |

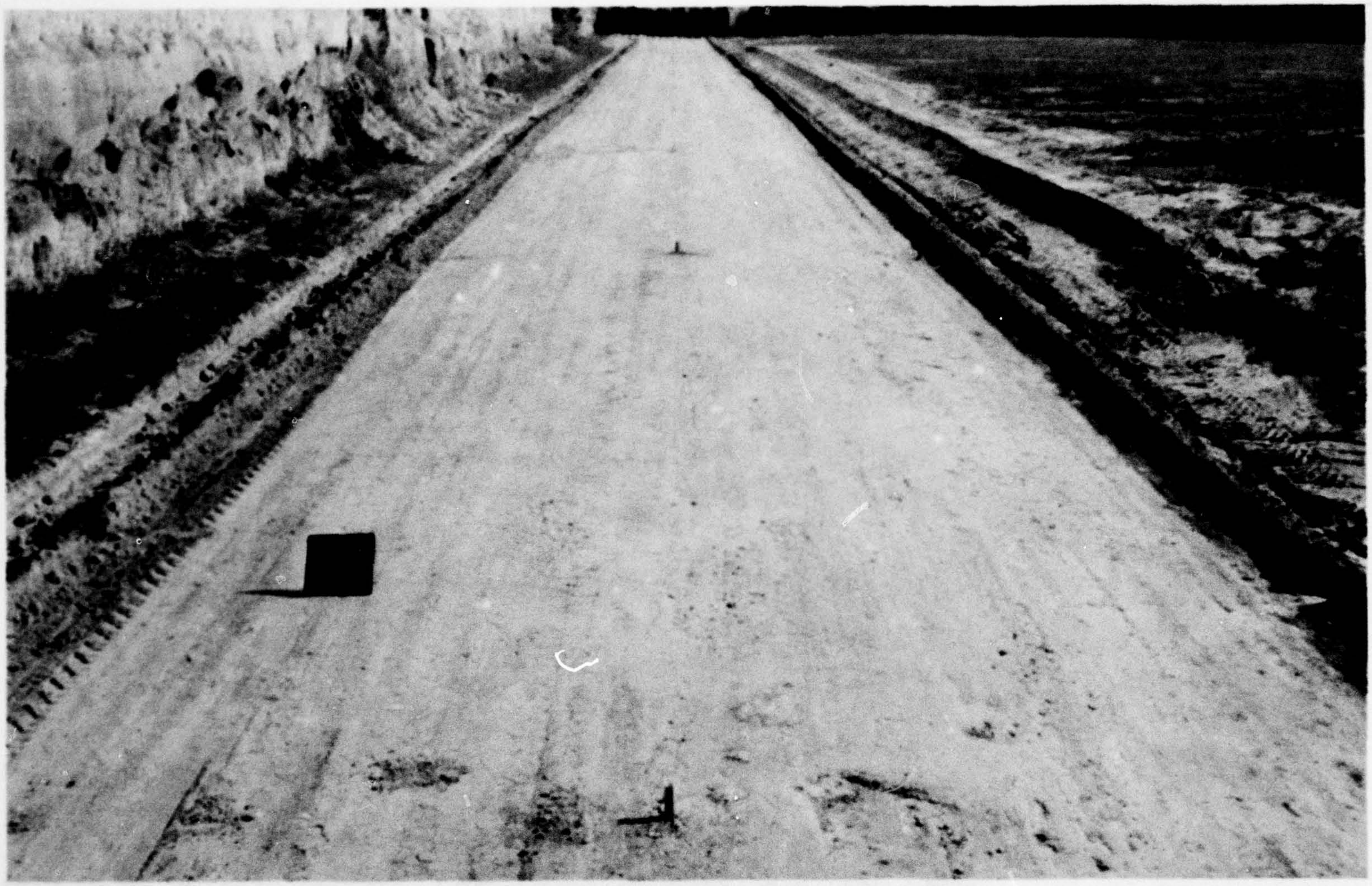

Photo 1. Finished subgrade

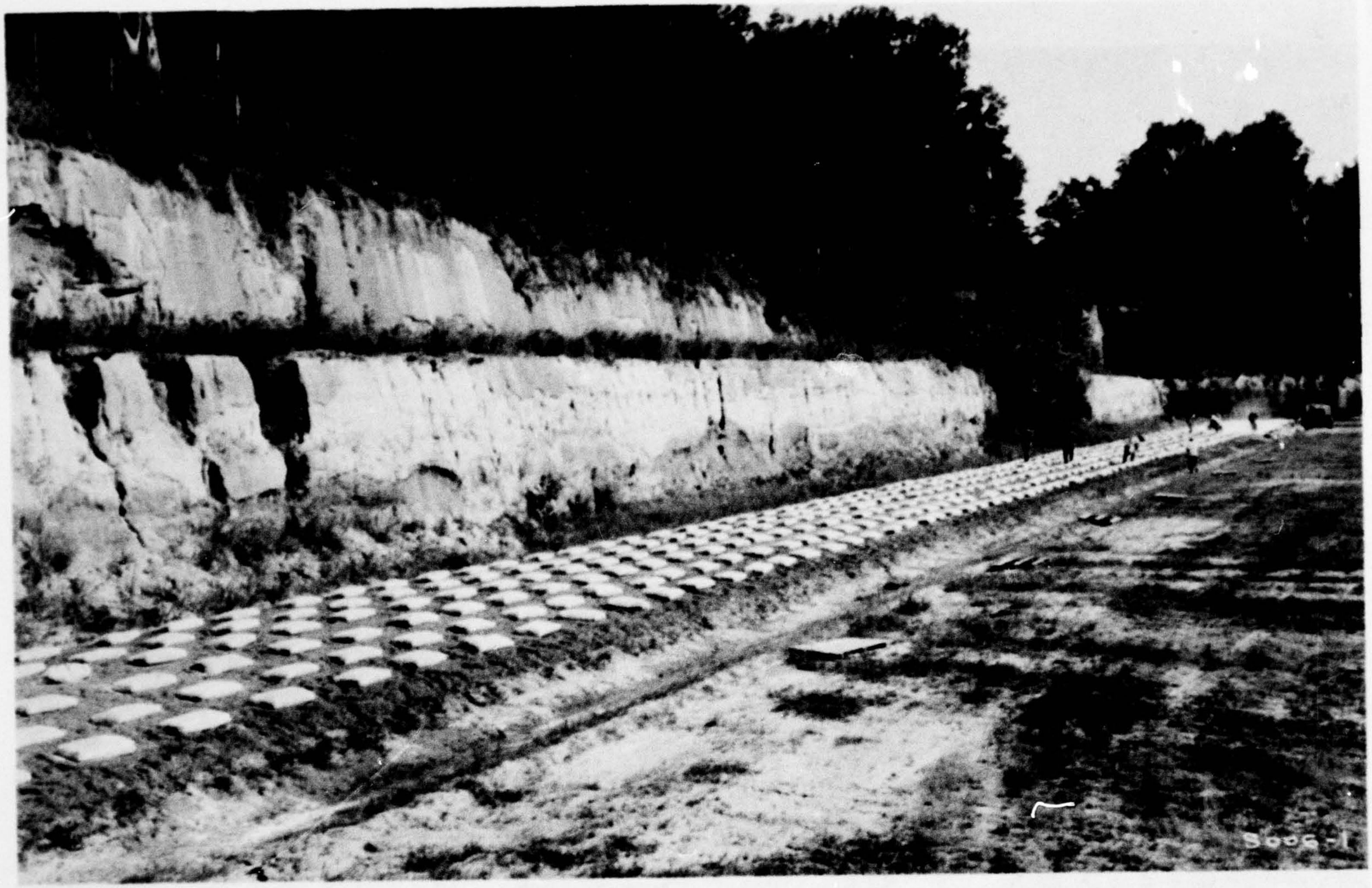

Photo 2. Bags of lime placed at predetermined intervals for desired percent of treatment

Photo 3. Mixing base material and lime

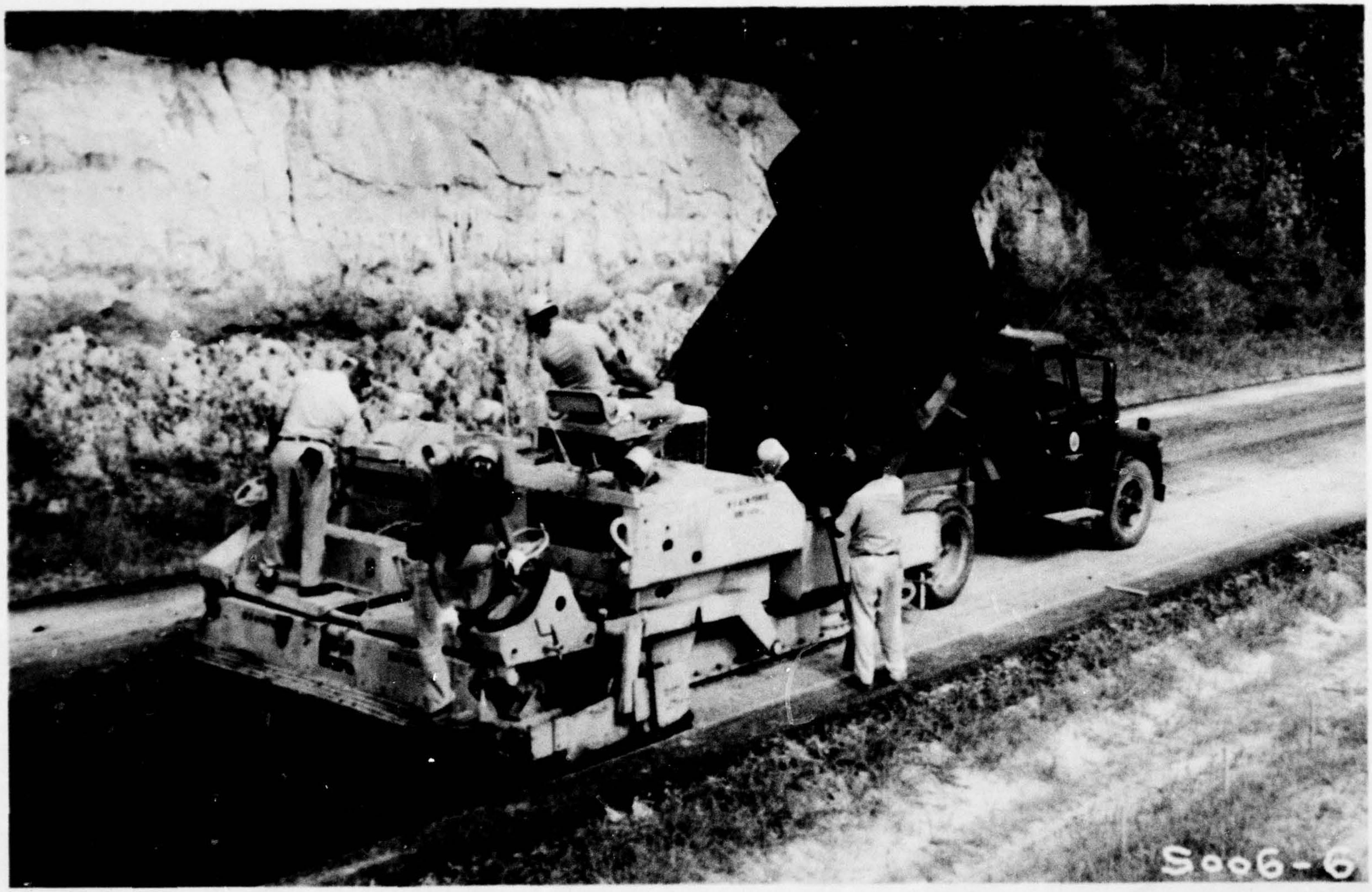


Photo 4. Placement of asphaltic concrete

AD-A078 725 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
UTILIZATION OF MARGINAL CONSTRUCTION MATERIALS FOR LOC. (U)
NOV 79 R W GRAU

UNCLASSIFIED WES/GL-79-21 NL

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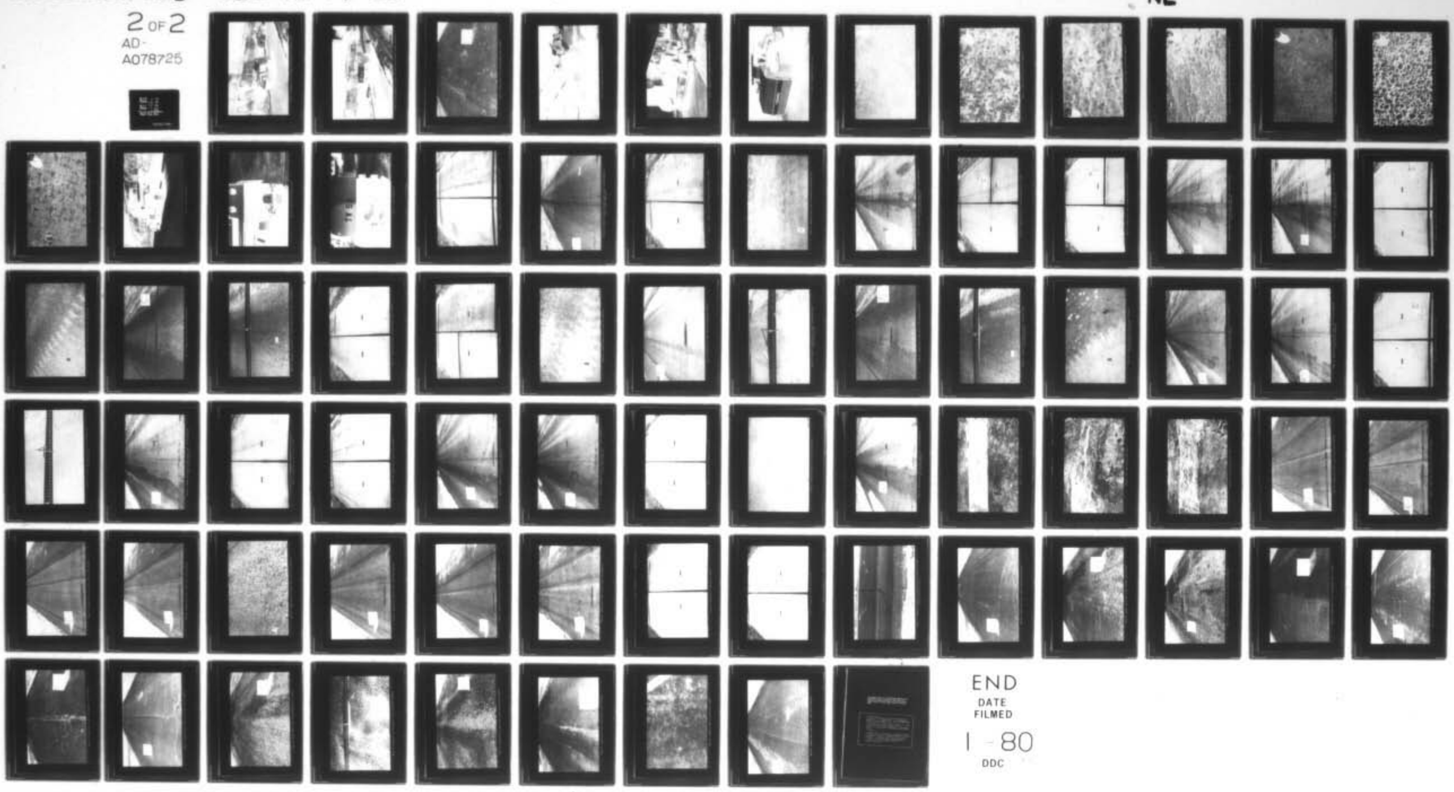

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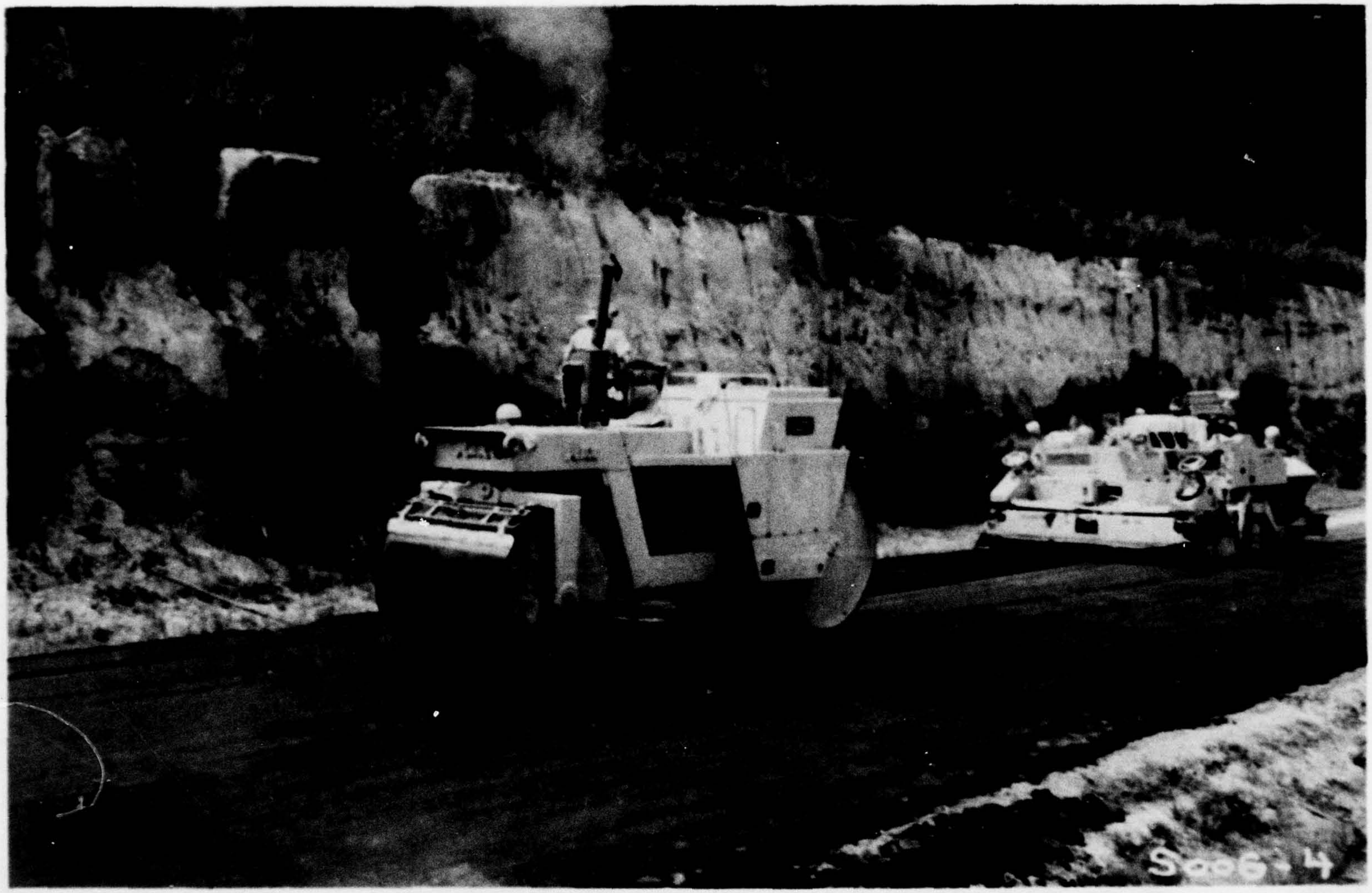


Photo 5. Breakdown rolling of asphaltic concrete with a steel-wheel roller

Photo 6. Final compaction of asphaltic concrete with a 47,000-lb rubber-tired roller

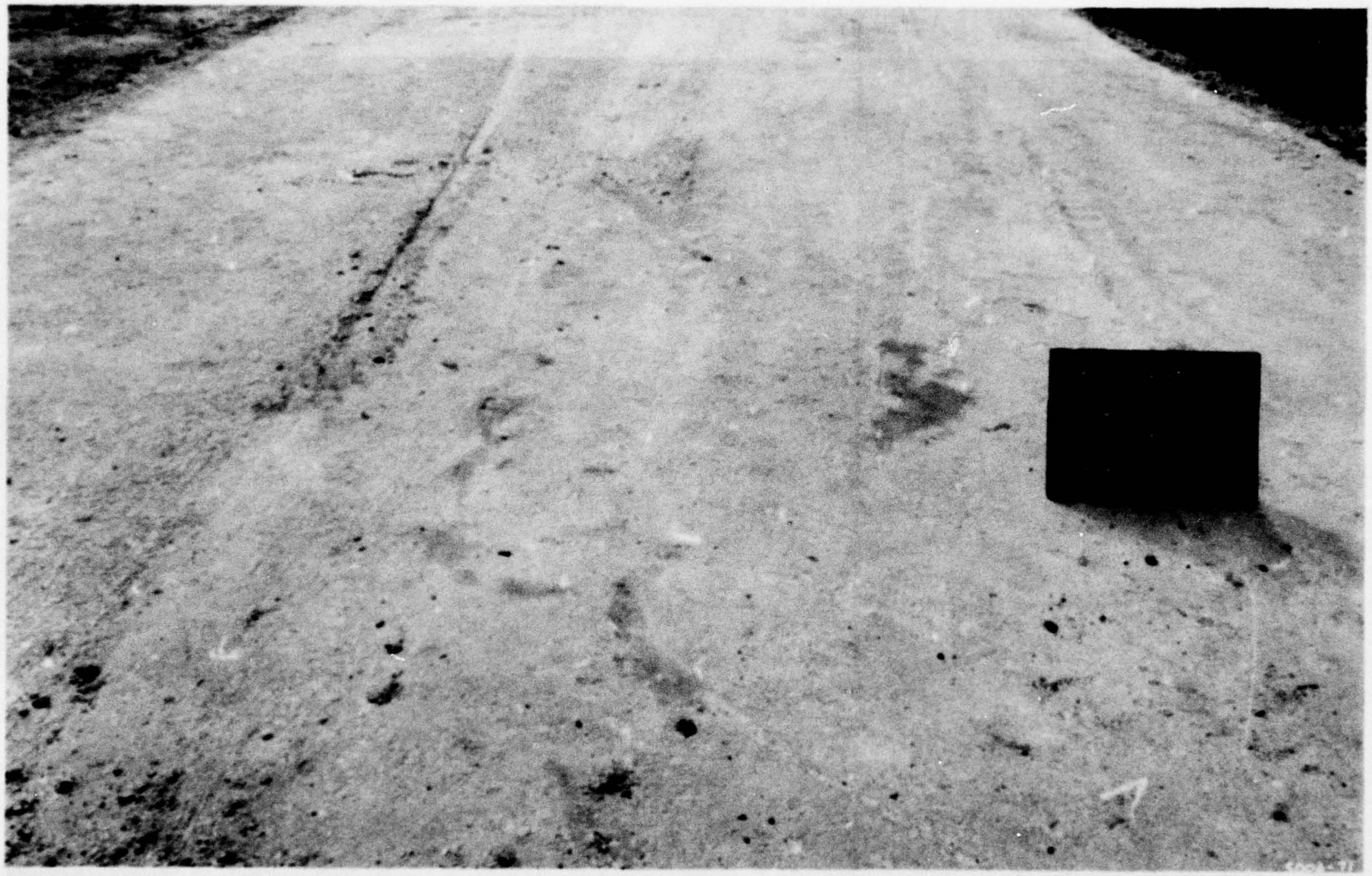

Photo 7. General view of item 1 (rigid pavement) prior to traffic


Photo 8. End dumping zero-slump mix in an asphalt finisher


Photo 9. Placement of zero-slump mix with an asphalt finisher


Photo 10. Bomag BW220R vibratory roller

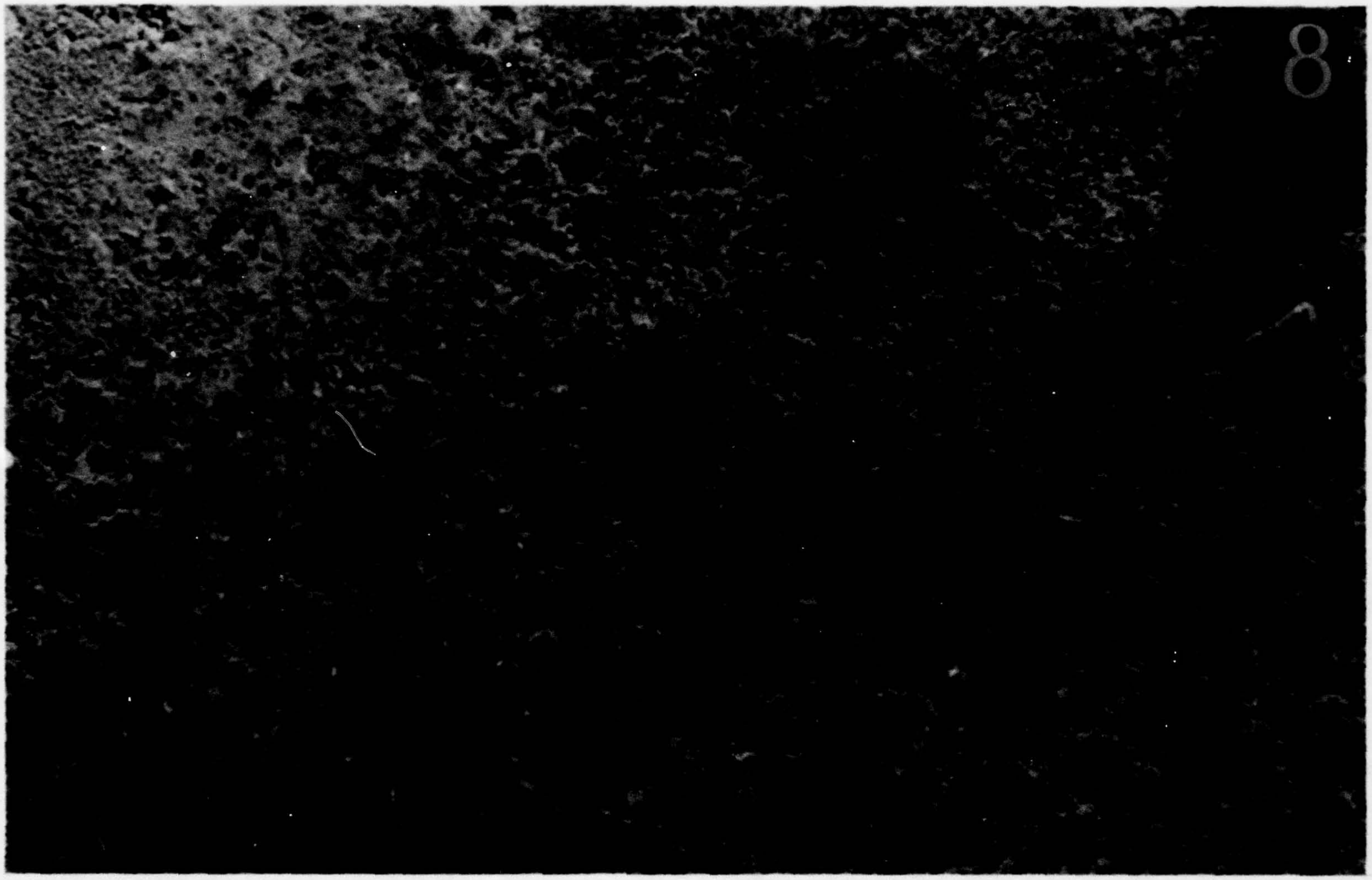


Photo 11. Surface texture of item 1 after compaction

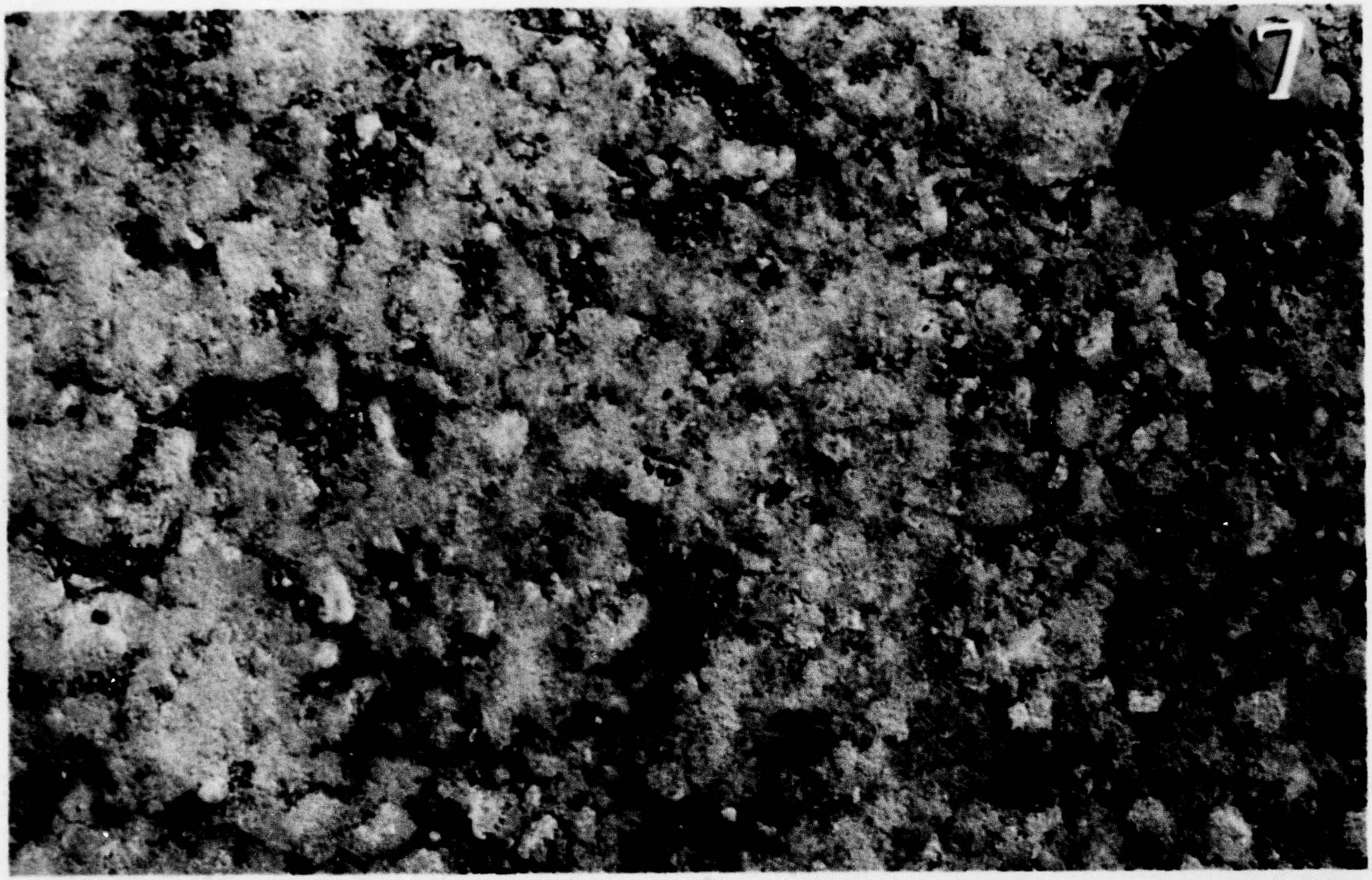


Photo 12. Surface texture of item 2 after compaction

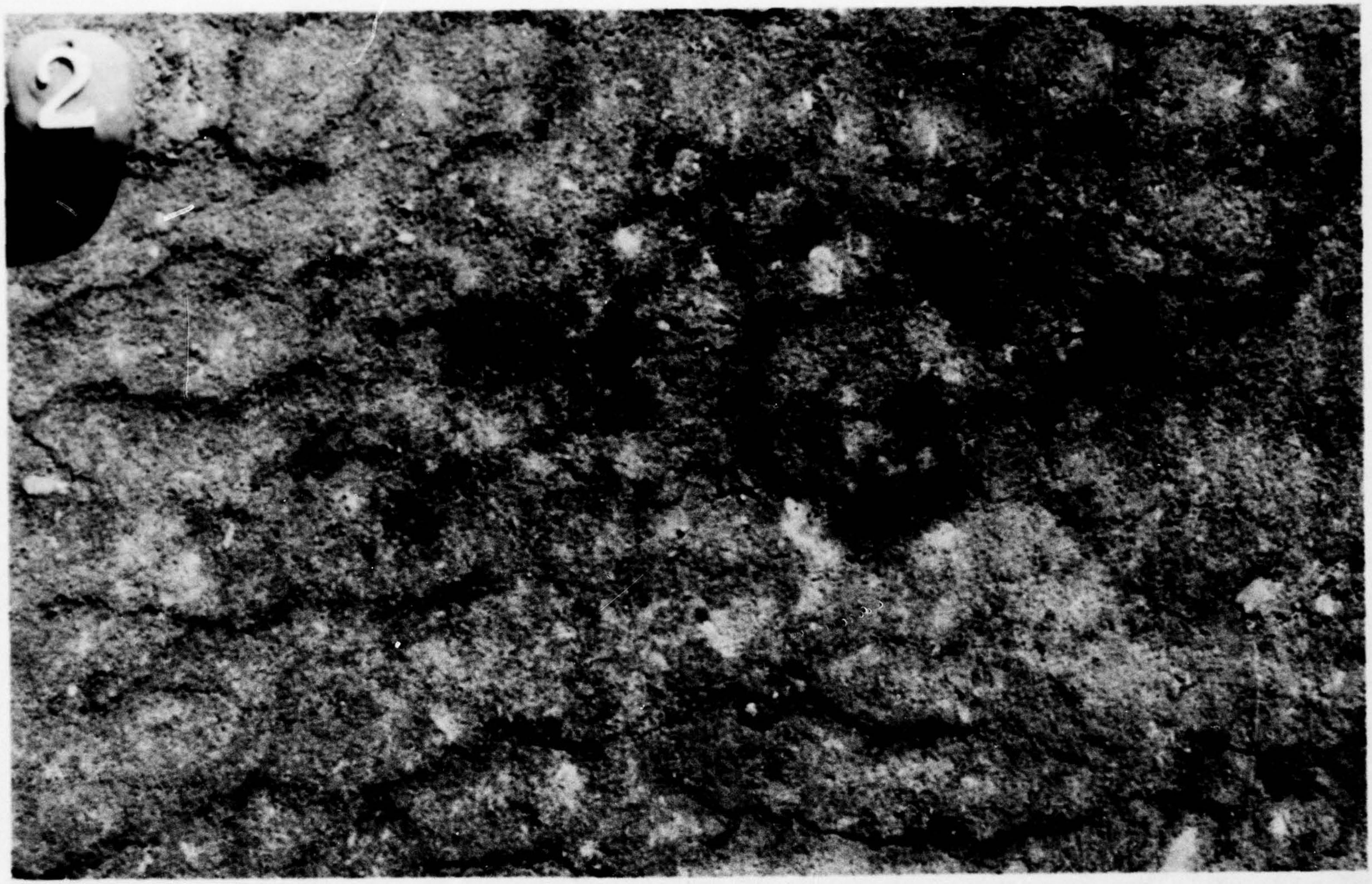


Photo 13. Surface texture of item 3 after compaction

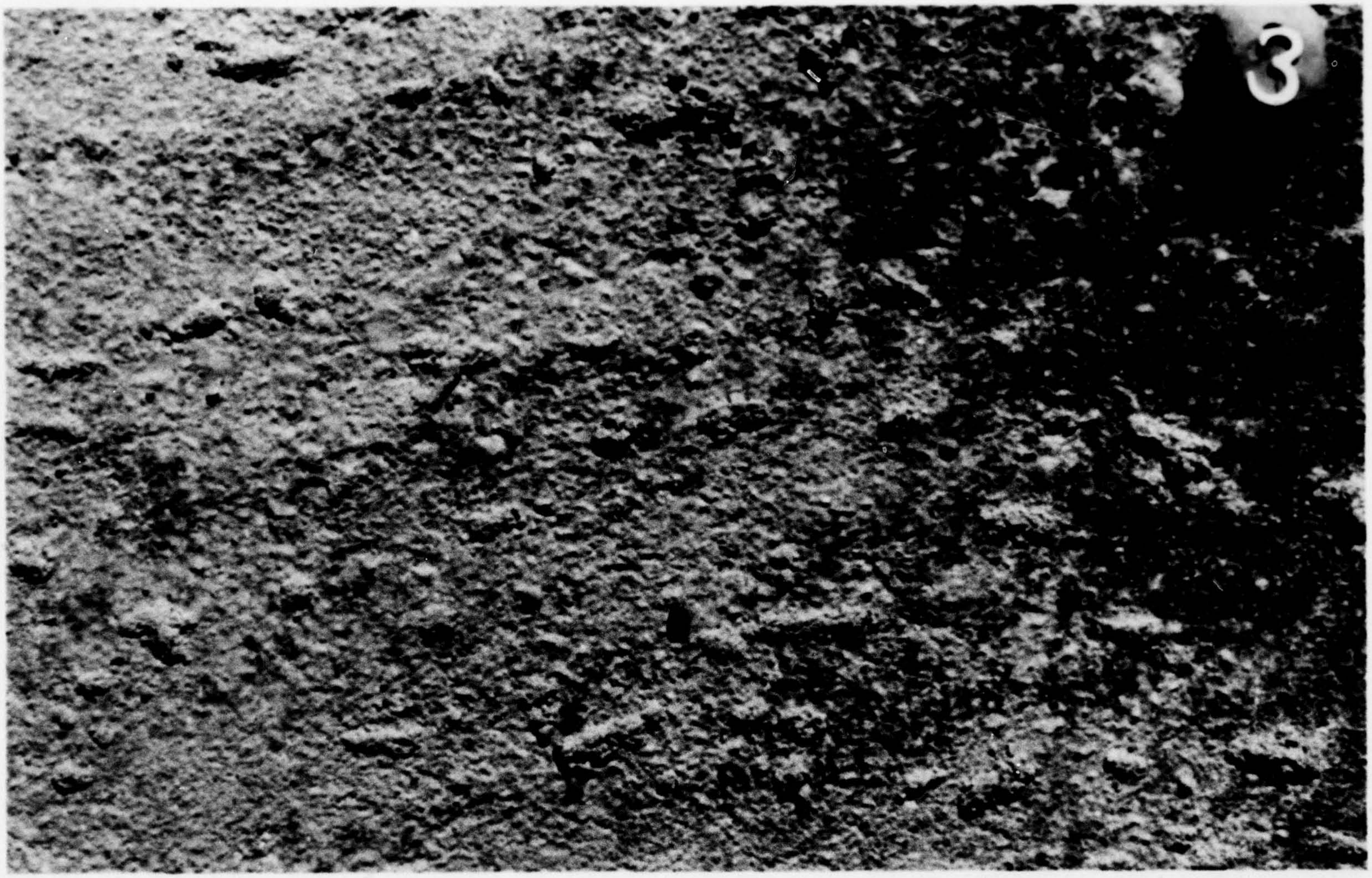


Photo 14. Surface texture of item 4 (first concrete placement lane) after compaction


Photo 15. Surface texture of item 4 (second concrete placement lane) after compaction


Photo 16. Surface texture of item 5 after compaction

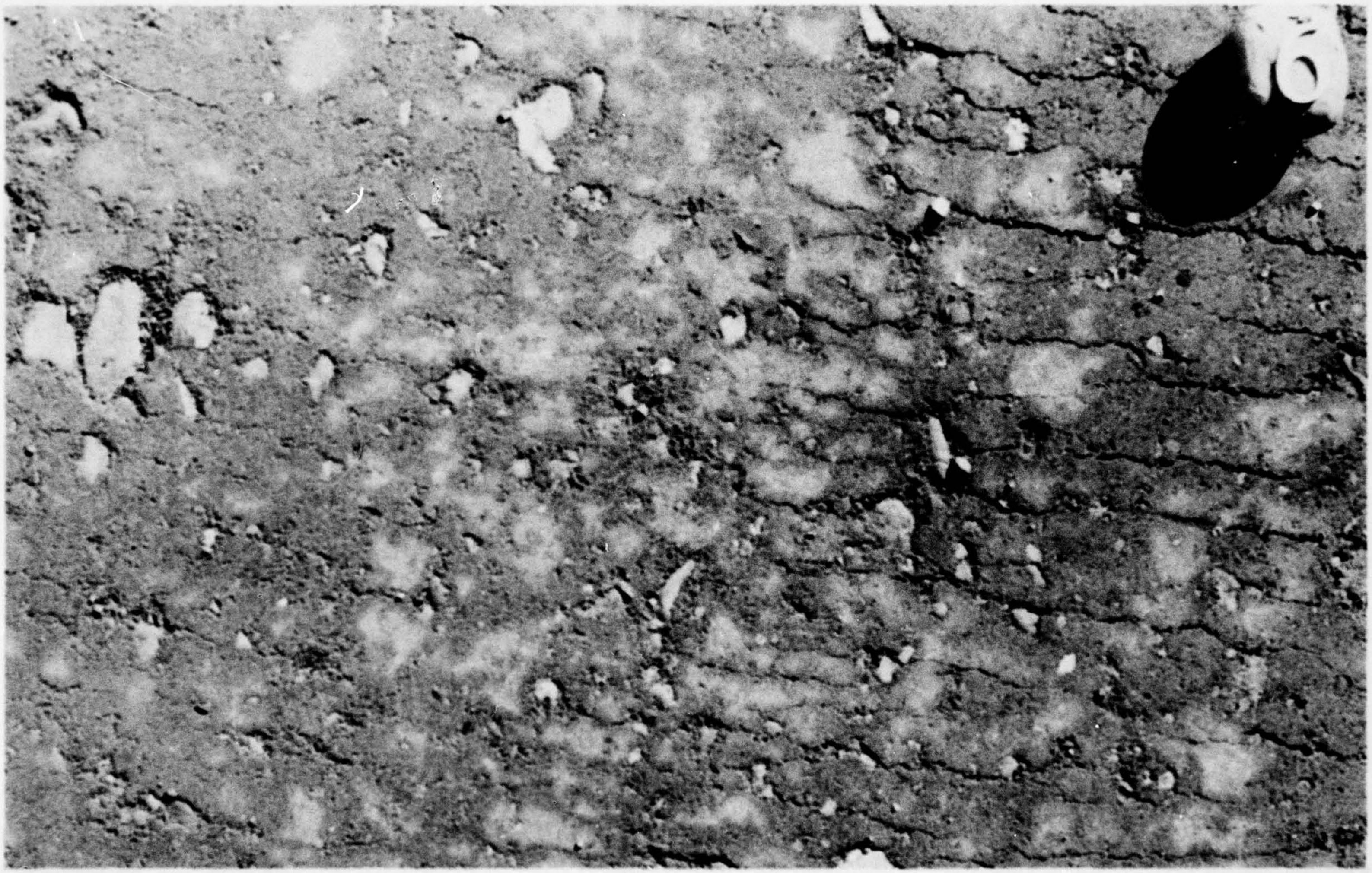

Photo 17. Surface texture of item 6 after compaction

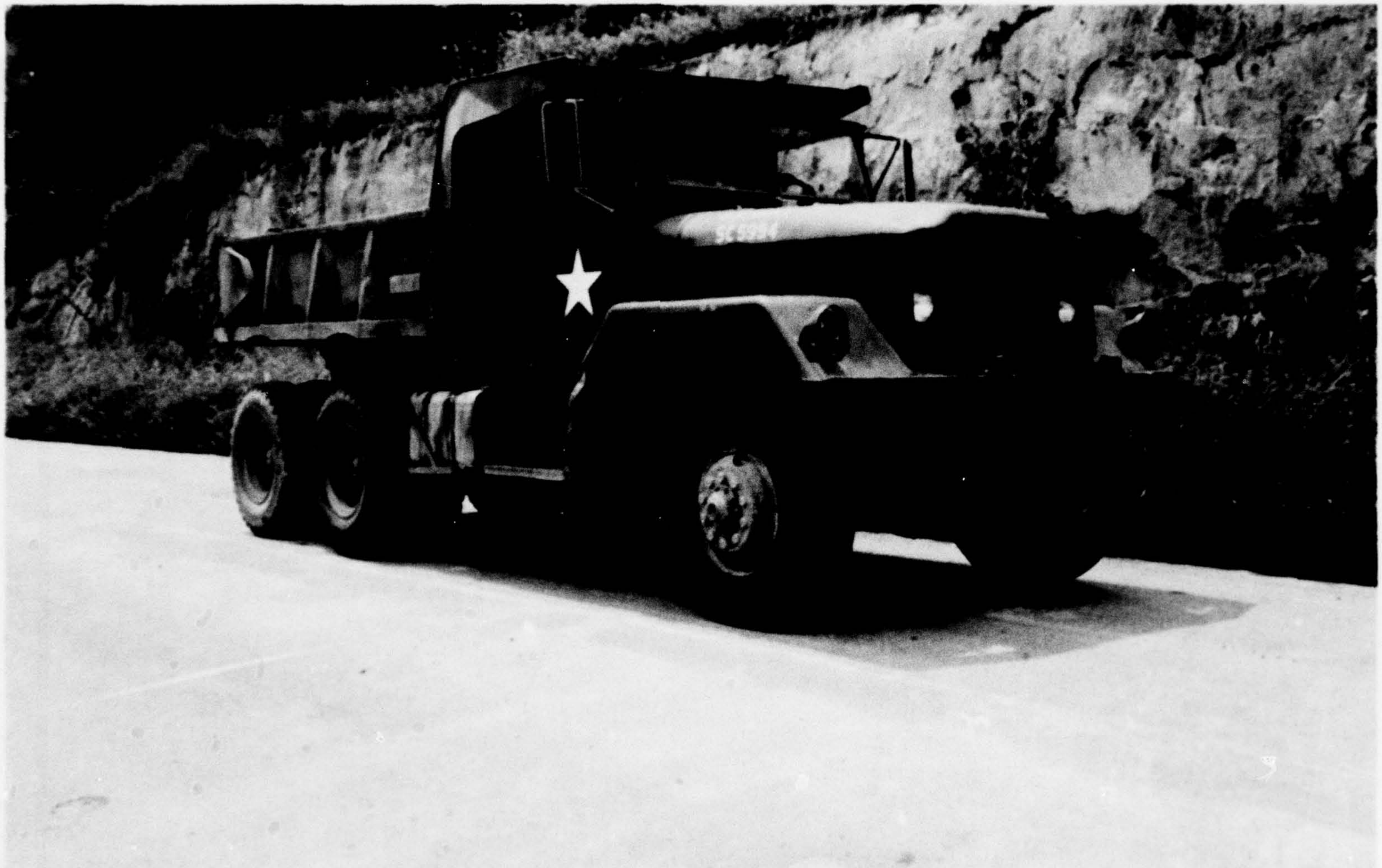

Photo 18. M51 5-ton dump truck

Photo 19. Track of M113 personnel carrier


Photo 20. Track of M48A1 tank

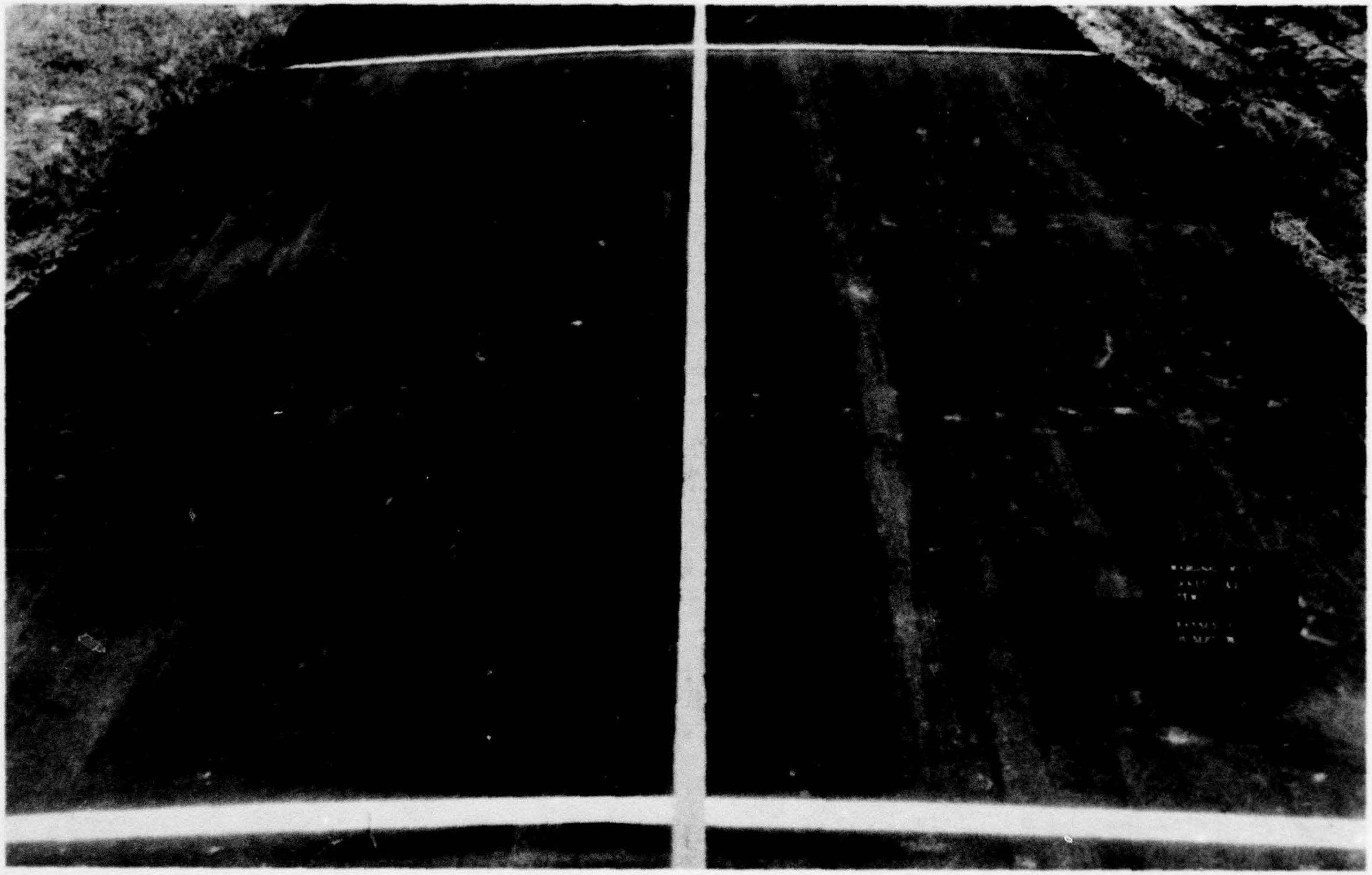

Photo 21. General view of item 1 (flexible pavement) prior to traffic


Photo 22. General view of item 1 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)


Photo 23. General view of item 2 (flexible pavement) prior to traffic

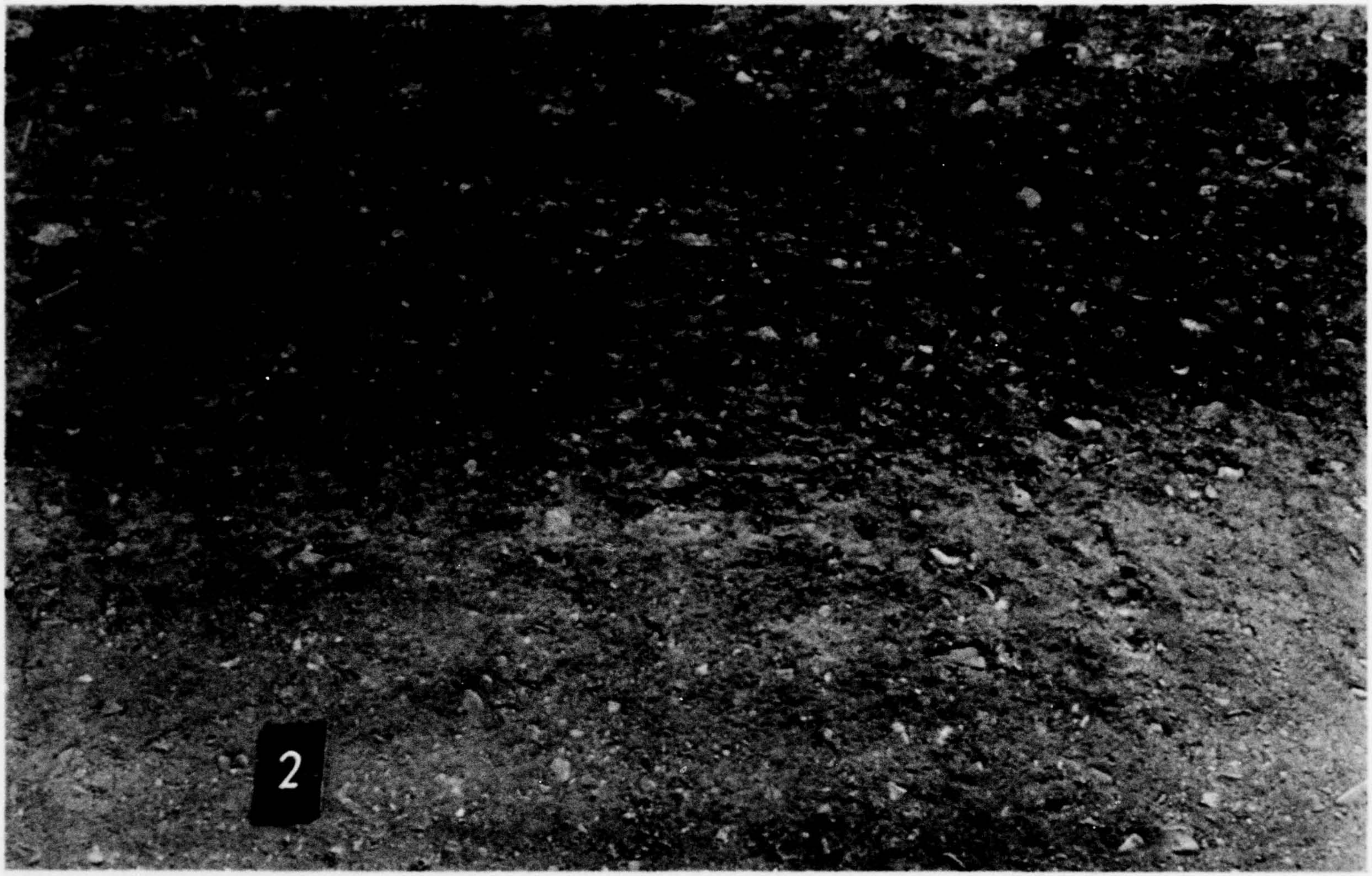


Photo 24. Shoving in item 2 after 8162 operations (outside wheel path)


Photo 25. General view of item 2 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

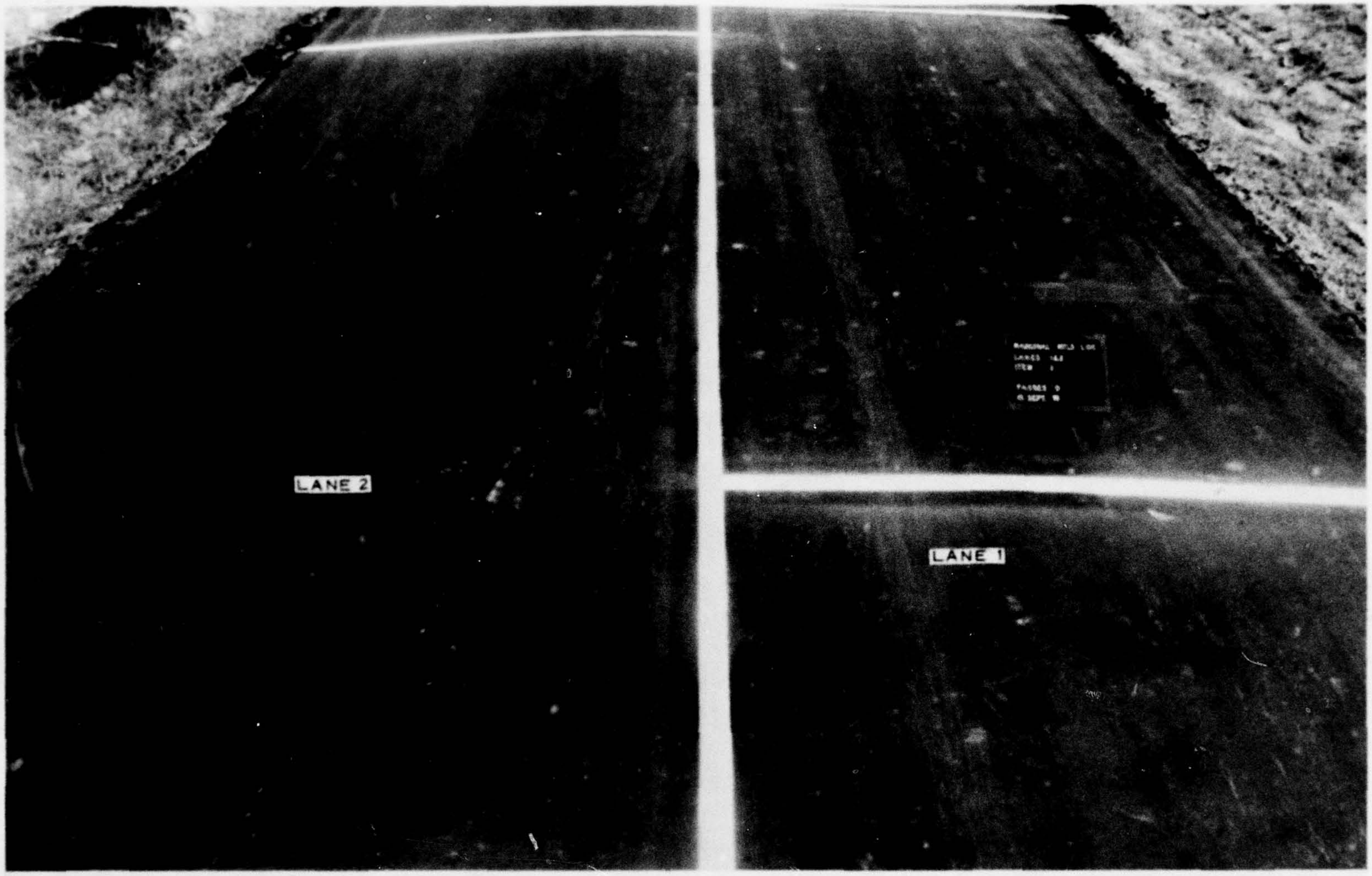


Photo 26. General view of item 3 (flexible pavement) prior to traffic

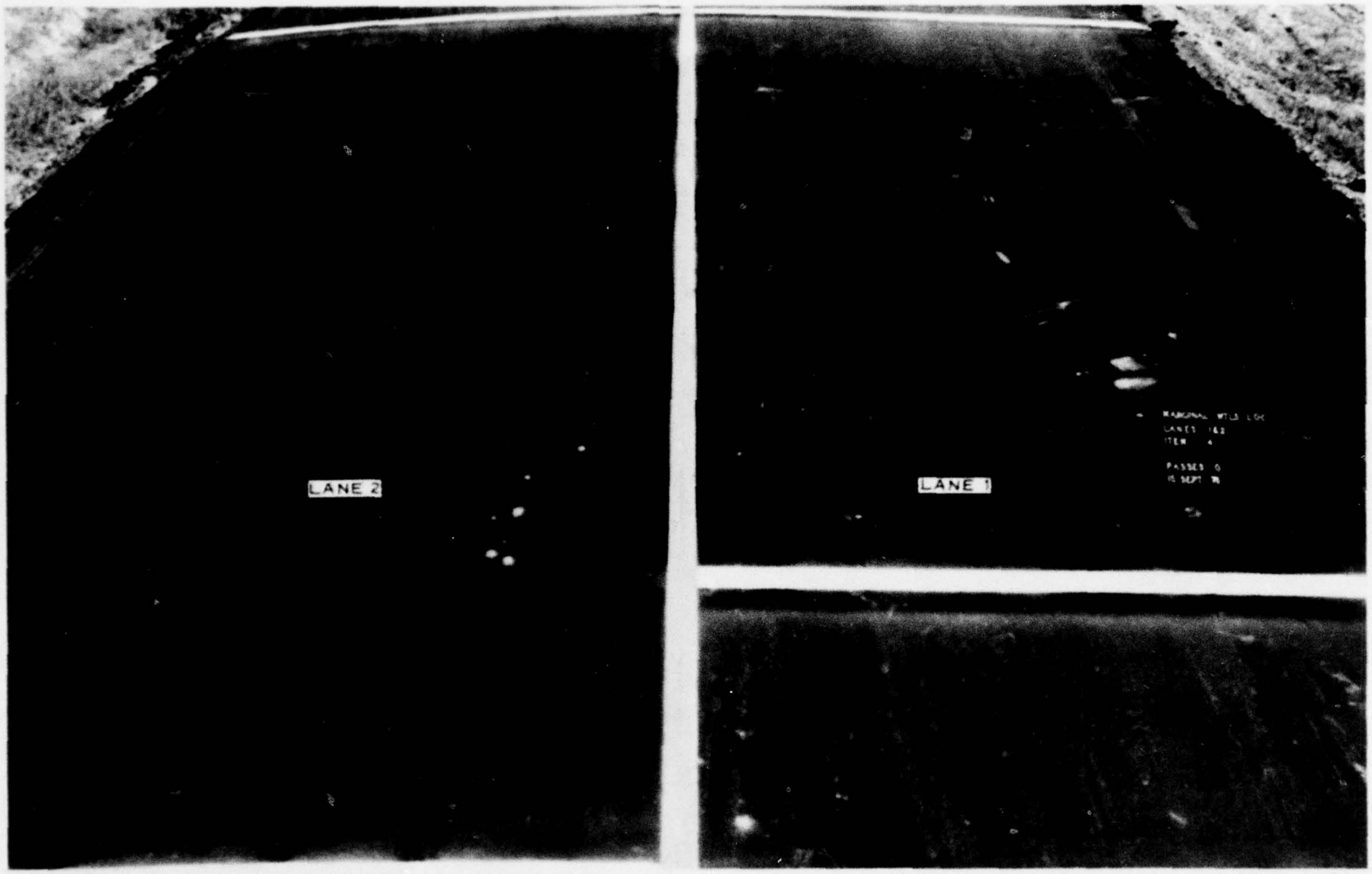


Photo 27. General view of item 4 (flexible pavement) prior to traffic


Photo 28. General view of item 3 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)


Photo 29. General view of item 4 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

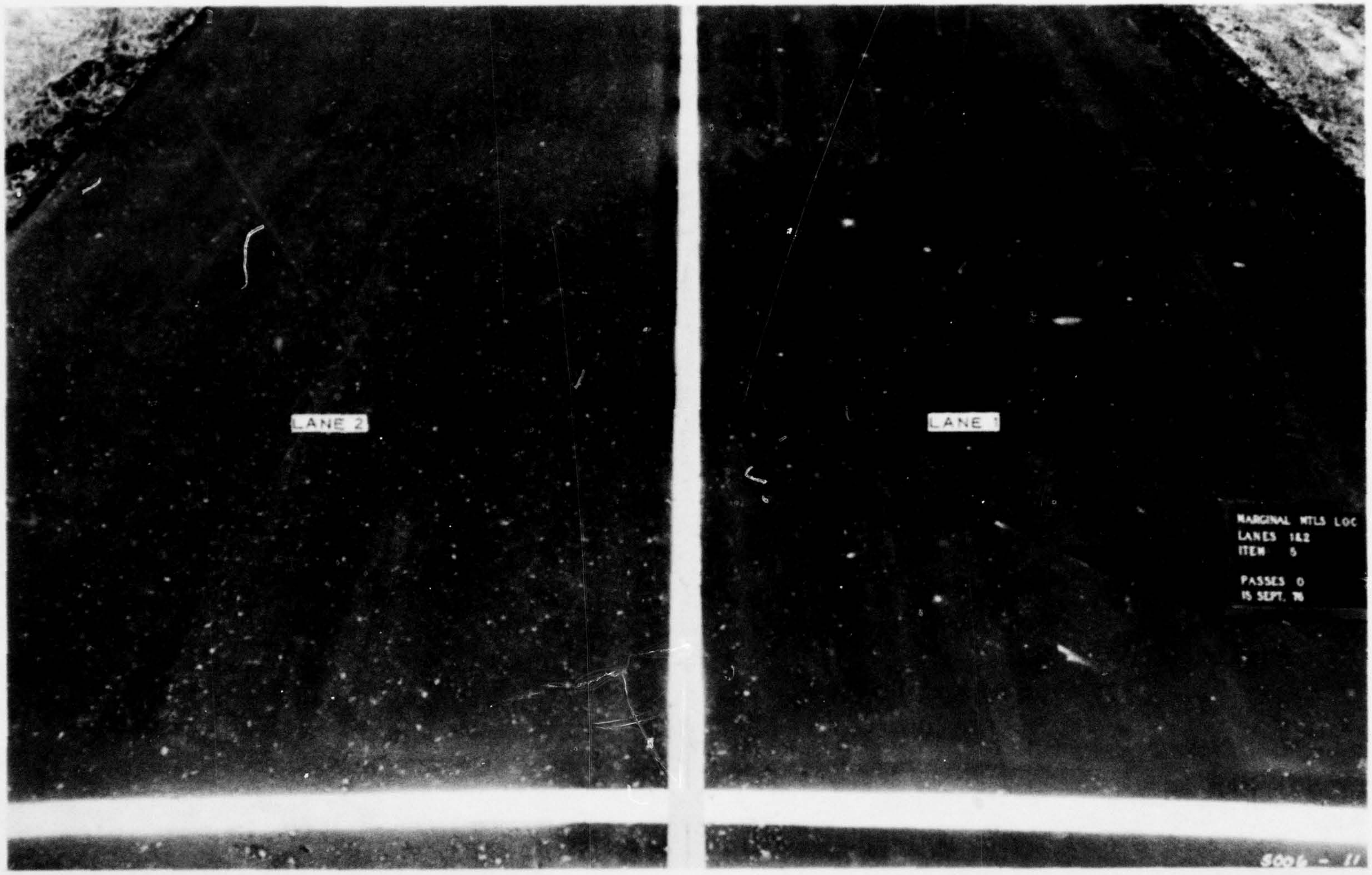


Photo 30. General view of item 5 (flexible pavement) prior to traffic

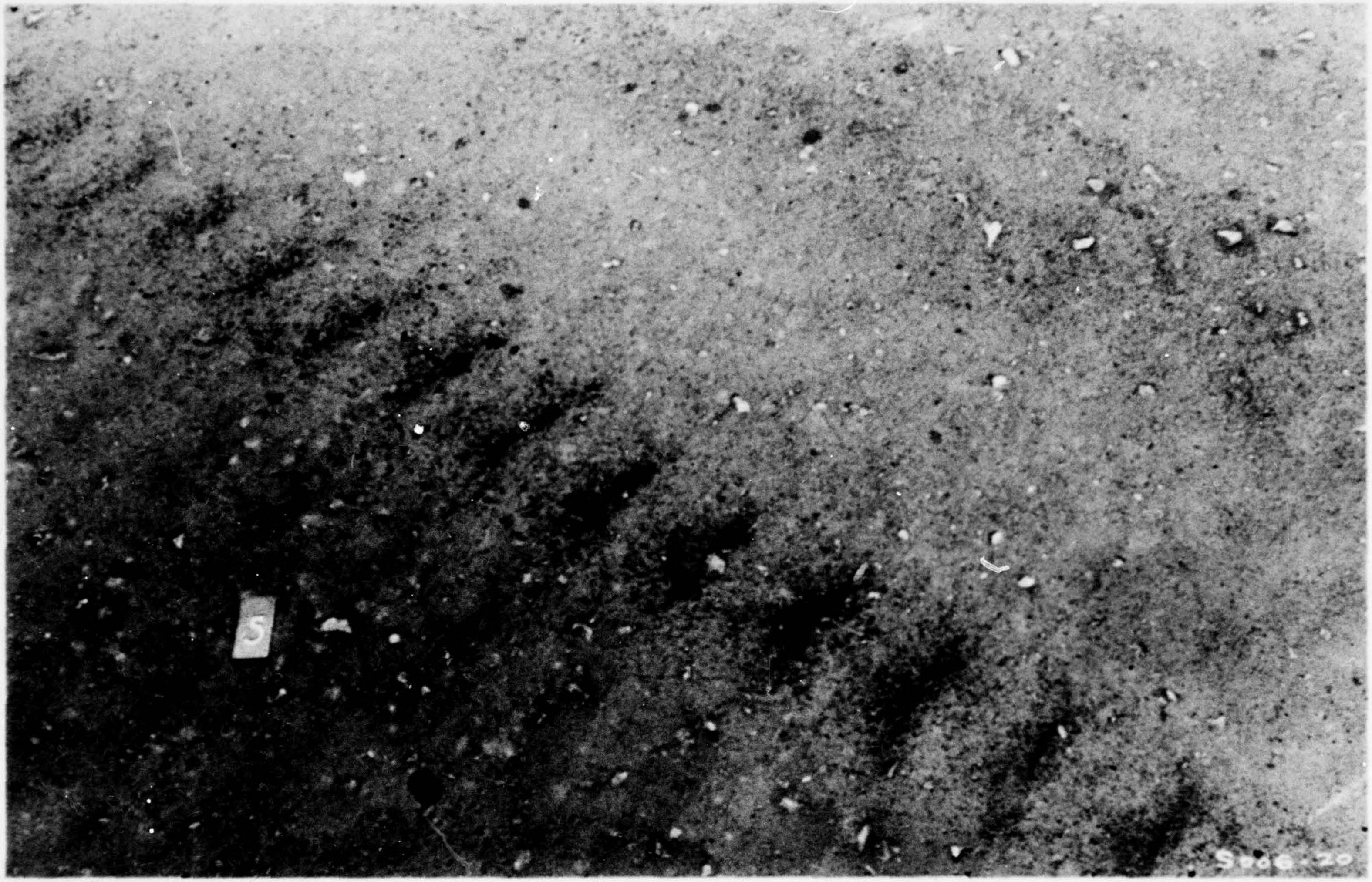


Photo 31. Raveling in item 5 after 1450 operations

Photo 32. General view of item 5 after 21,288 operations

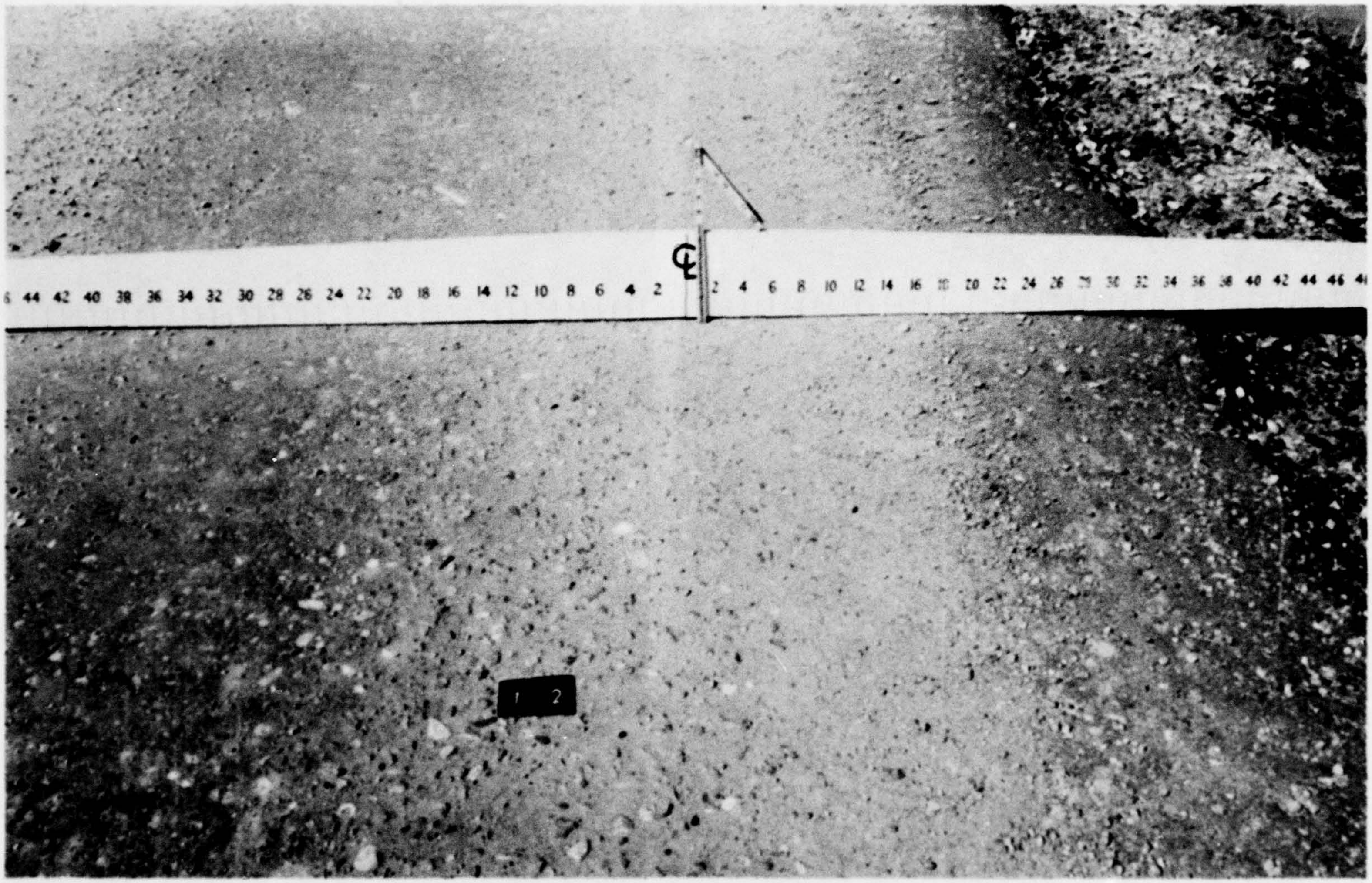

Photo 33. Close-up of 1/4-in.-deep rut in item 5 (outside wheel path) after 21,288 operations

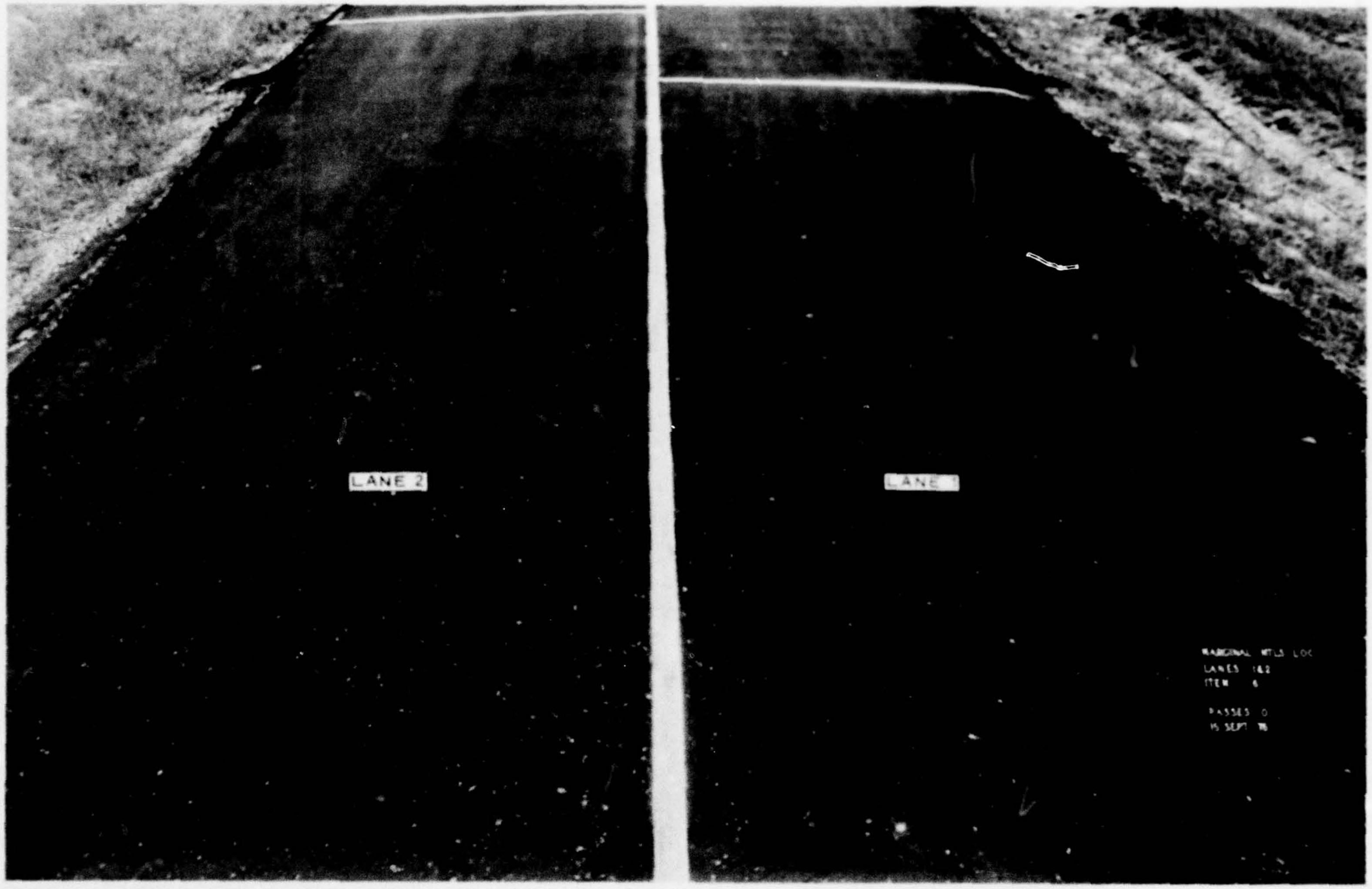


Photo 34. General view of item 6 (flexible pavement) prior to traffic

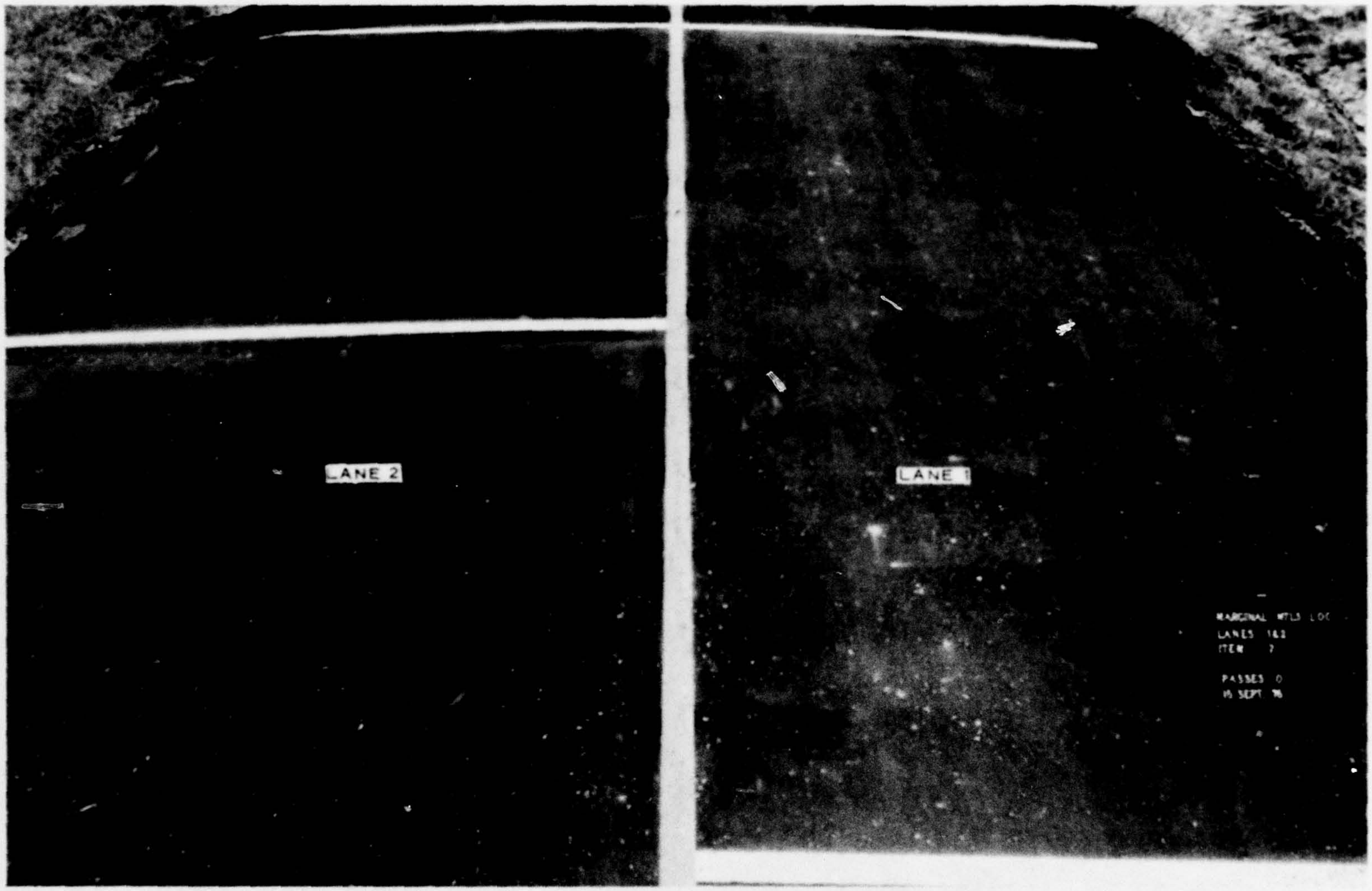


Photo 35. General view of item 7 prior to traffic

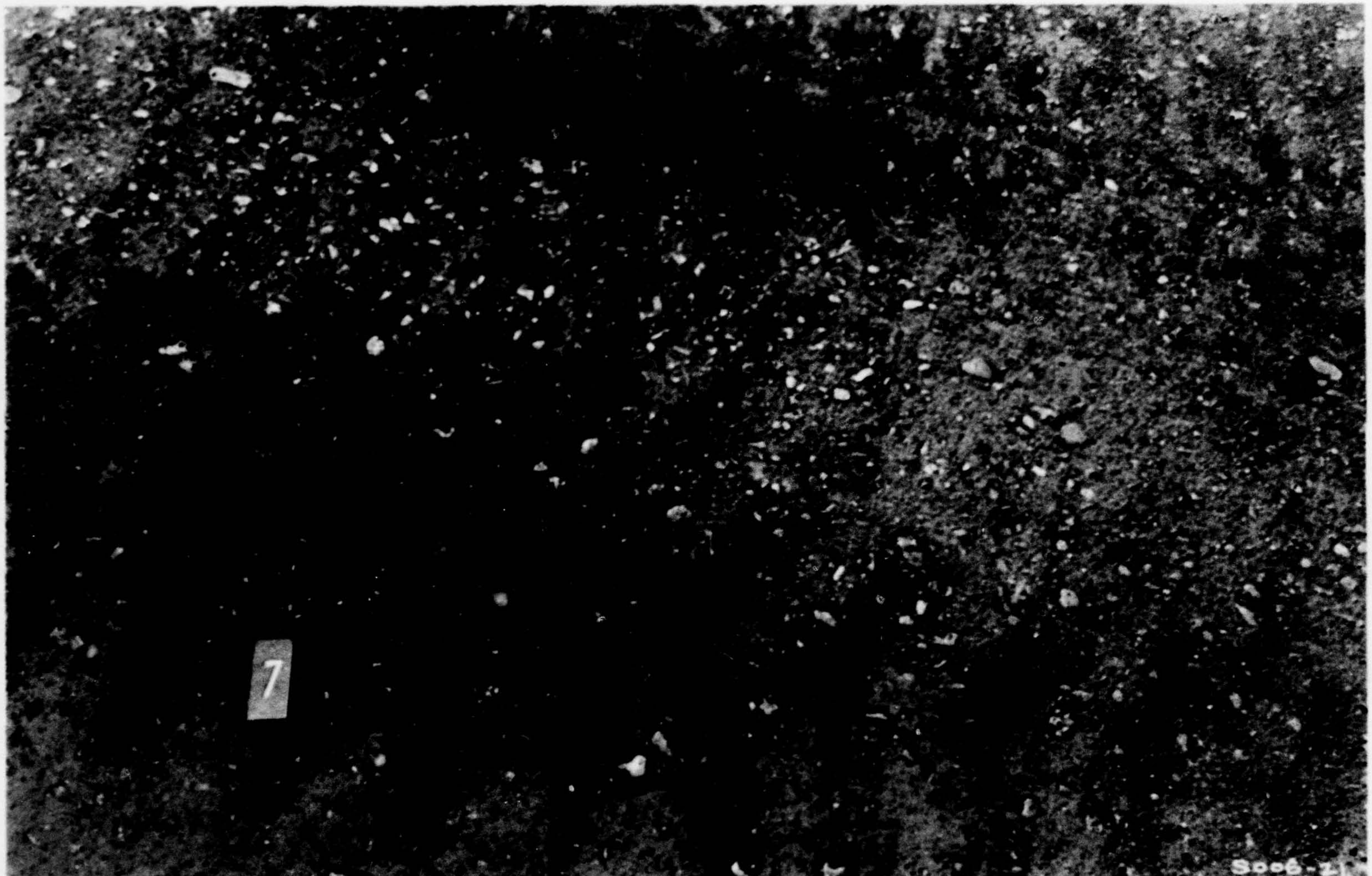

Photo 36. Surface raveling in item 7 after 1450 operations

Photo 37. General view of item 7 after 14,323 operations (failure)

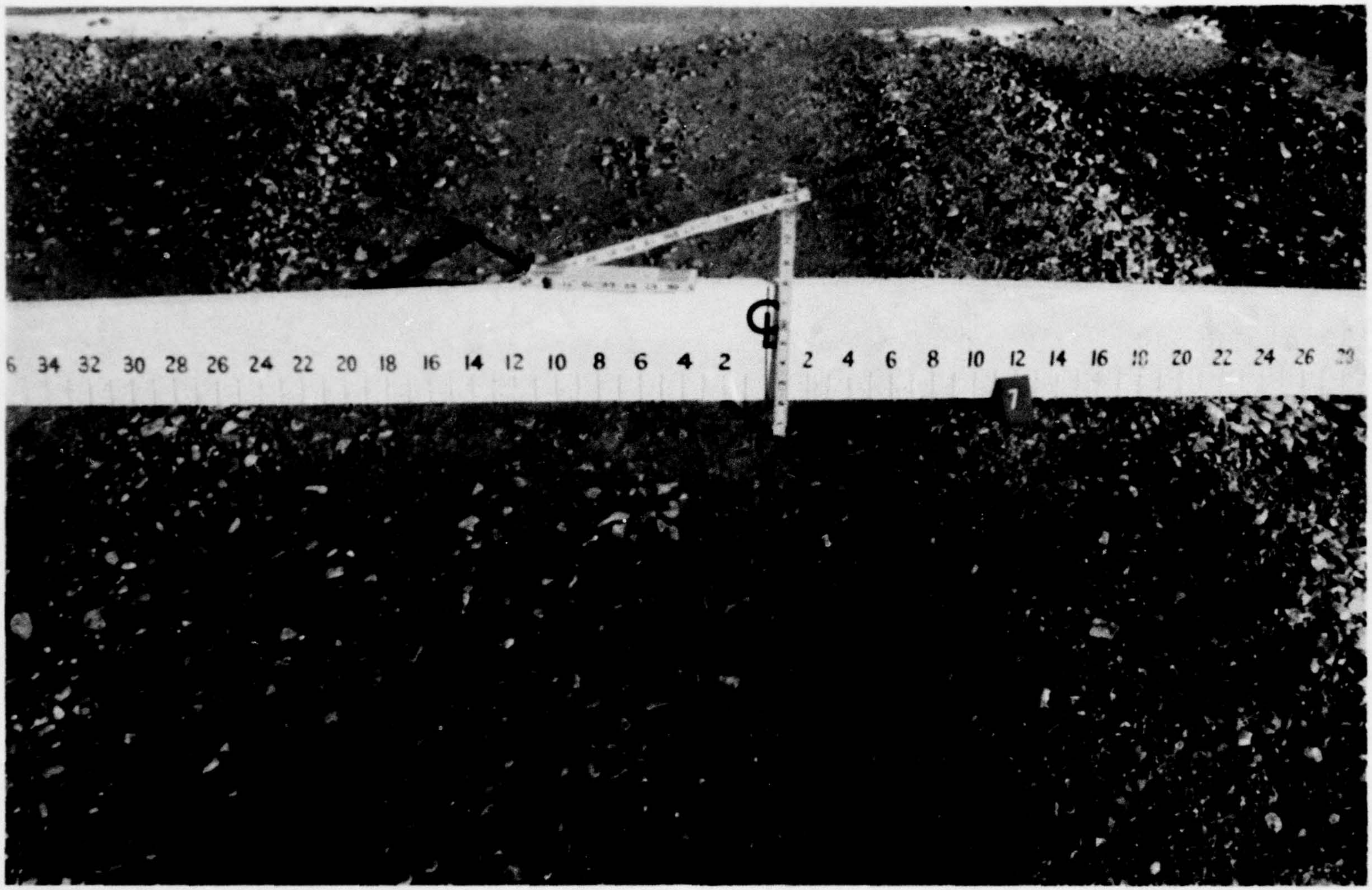

Photo 38. Close-up of 2-in.-deep rut in item 7 (outside wheel path) after 14,323 operations


Photo 39. General view of item 6 after 21,288 operations (failure)

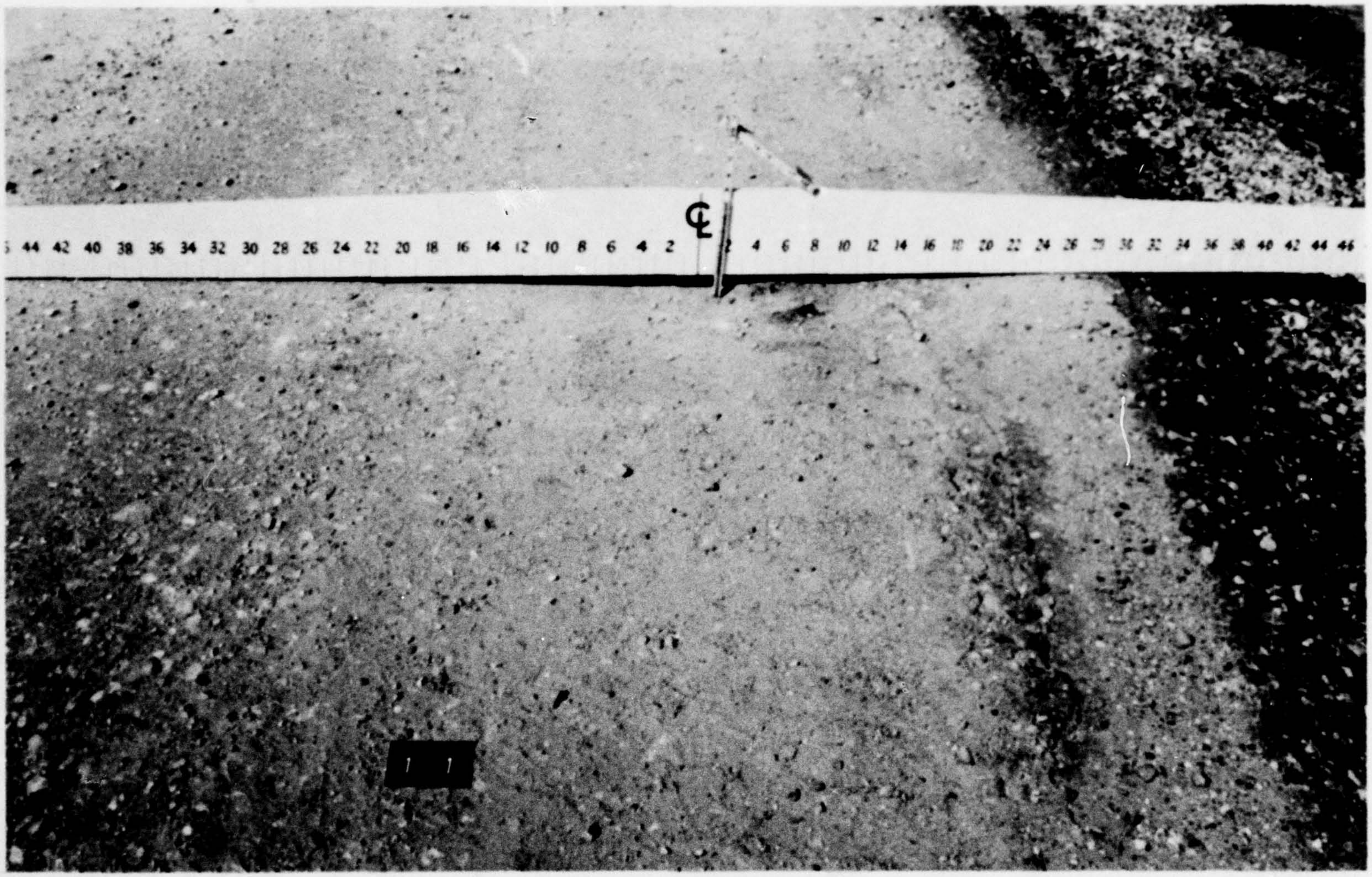

Photo 40. Close-up of 2-in.-deep rut in item 6 (outside wheel path) after 21,288 operations

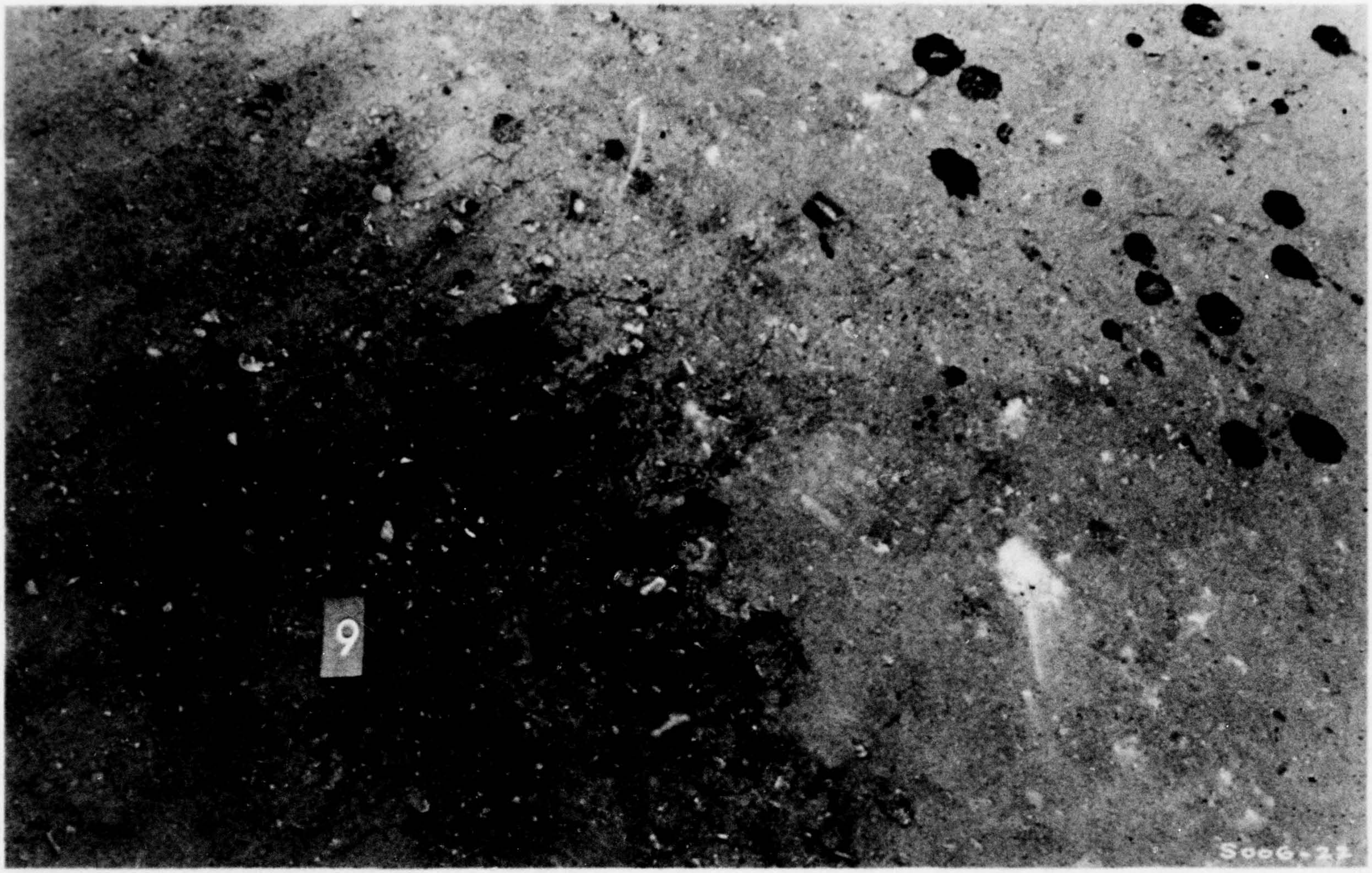


Photo 41. Close-up of outside wheel path in item 9 indicating tire imprints after 1450 operations

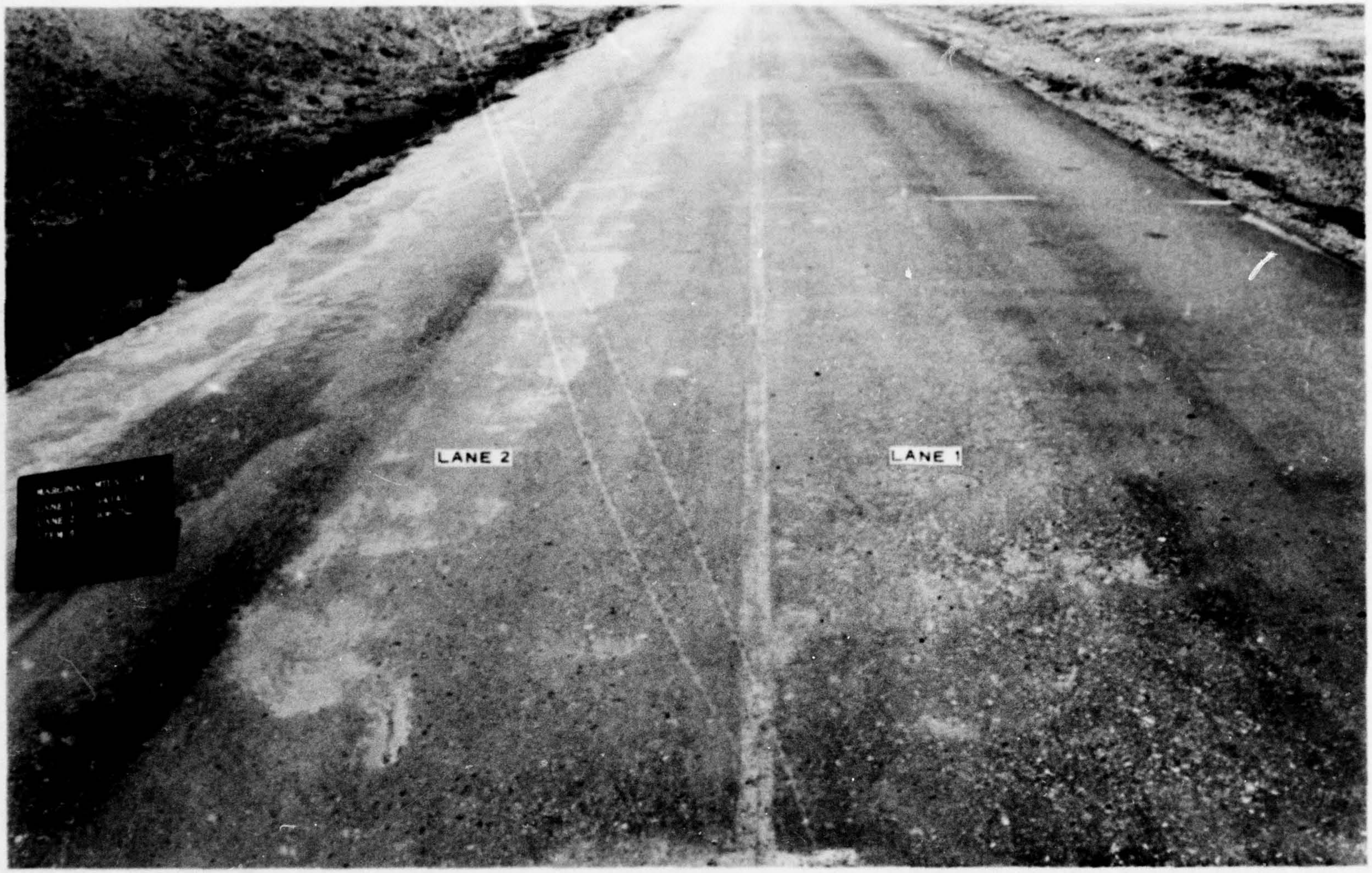


Photo 42. General view of item 8 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)


Photo 43. General view of item 9 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

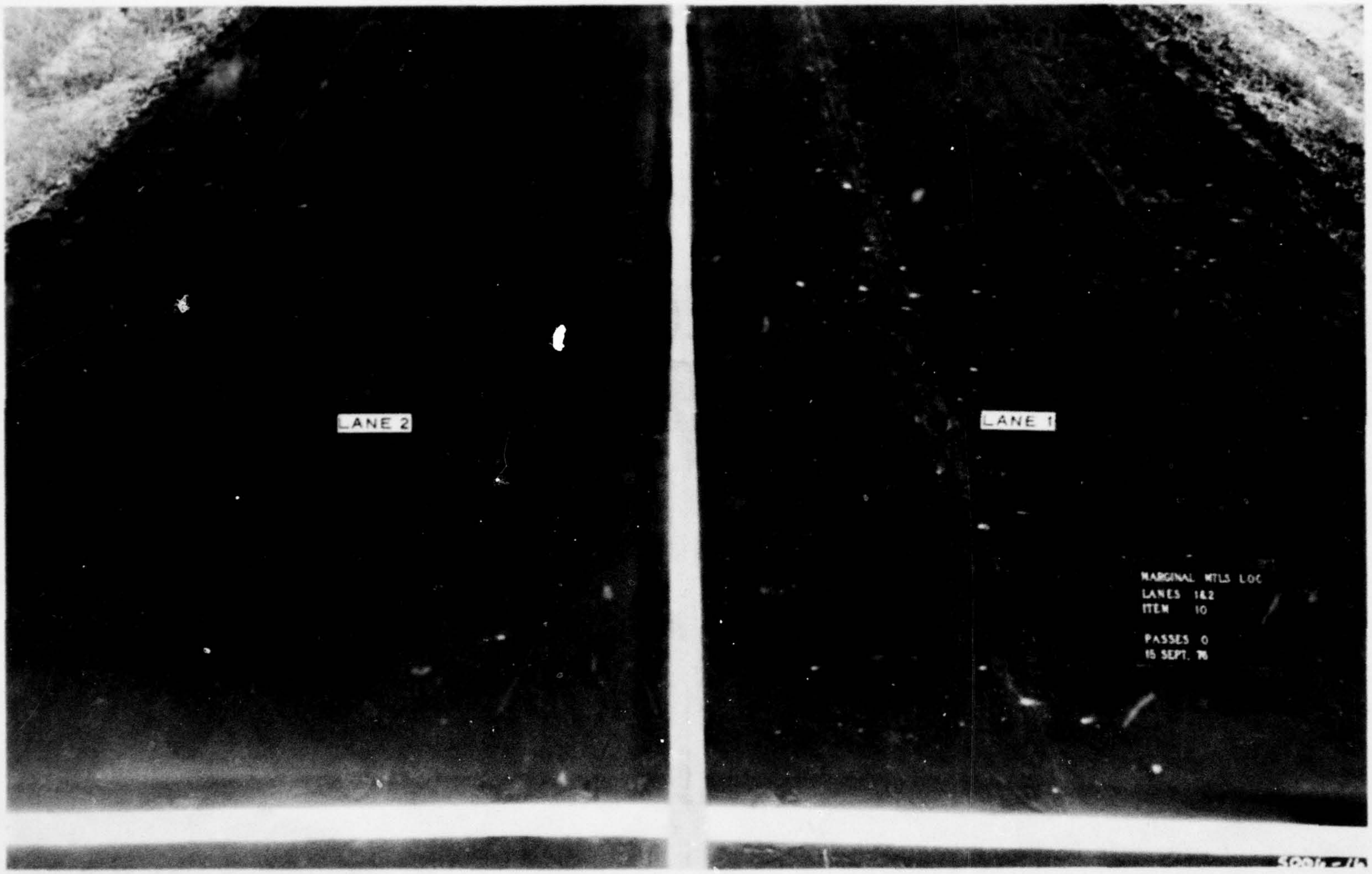


Photo 44. General view of item 10 prior to traffic

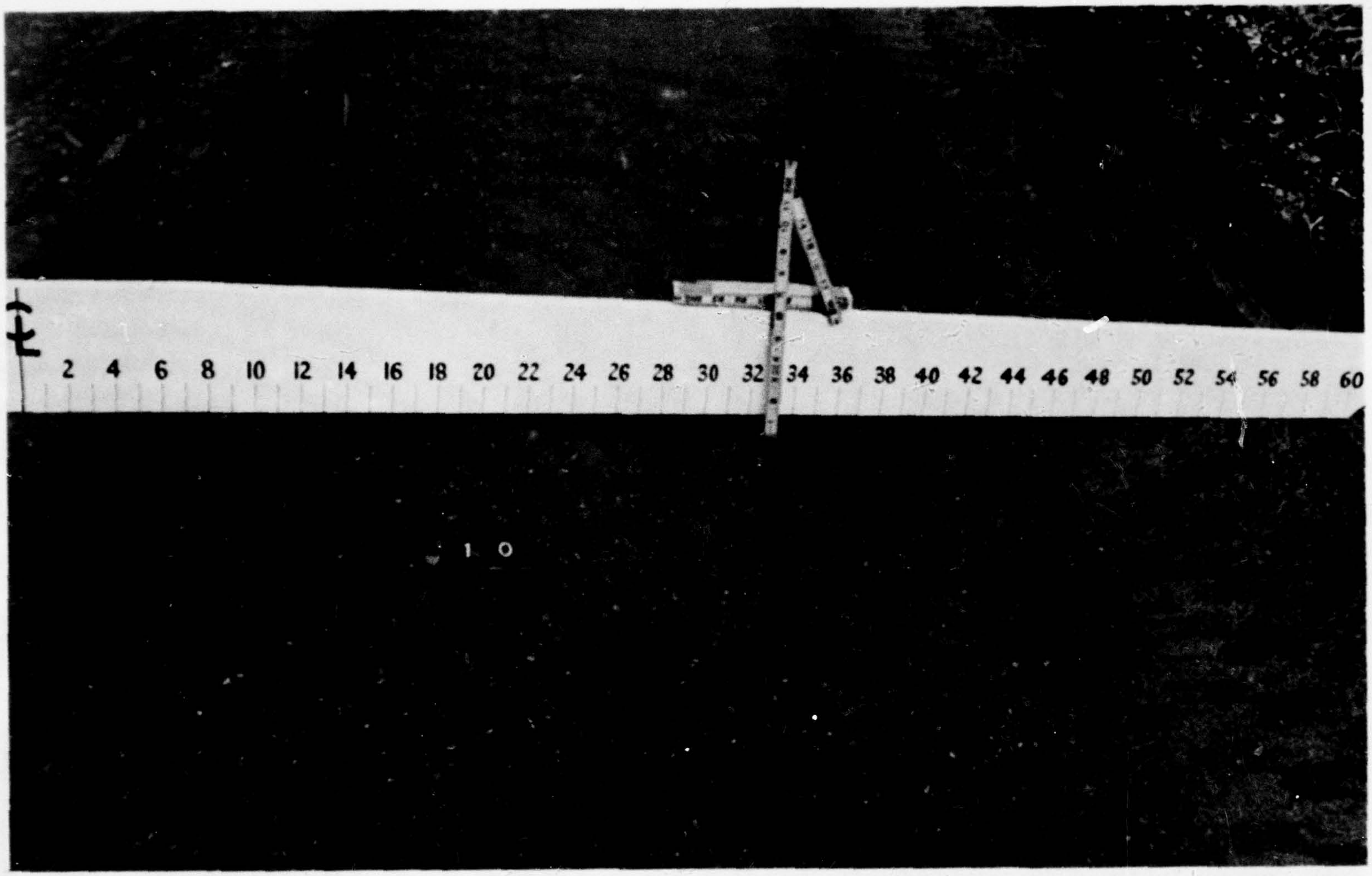


Photo 45. Close-up of 1-in.-deep rut in item 10 (outside wheel path) after 8162 operations


Photo 46. General view of item 10 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

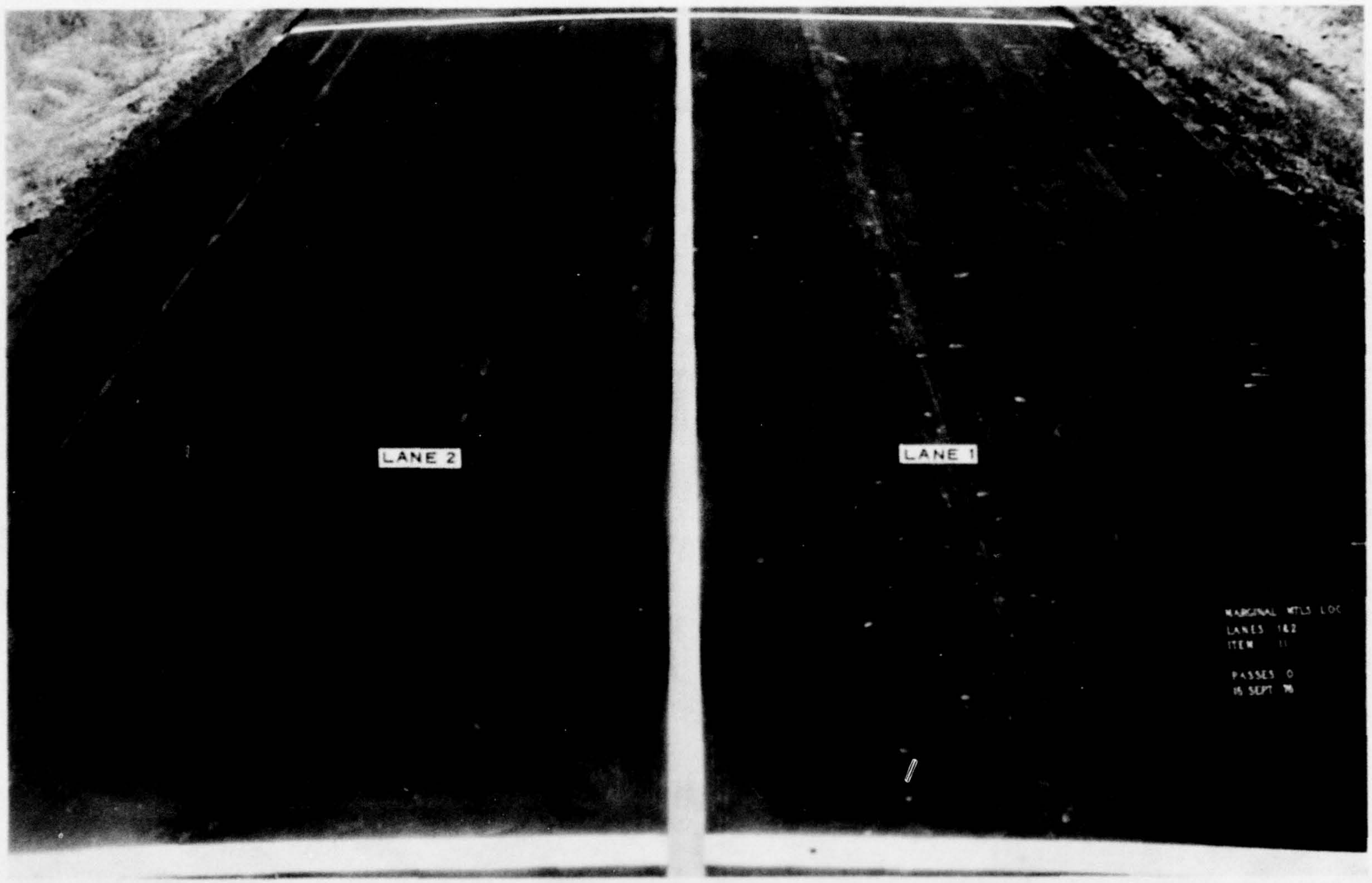


Photo 47. General view of item 11 prior to traffic

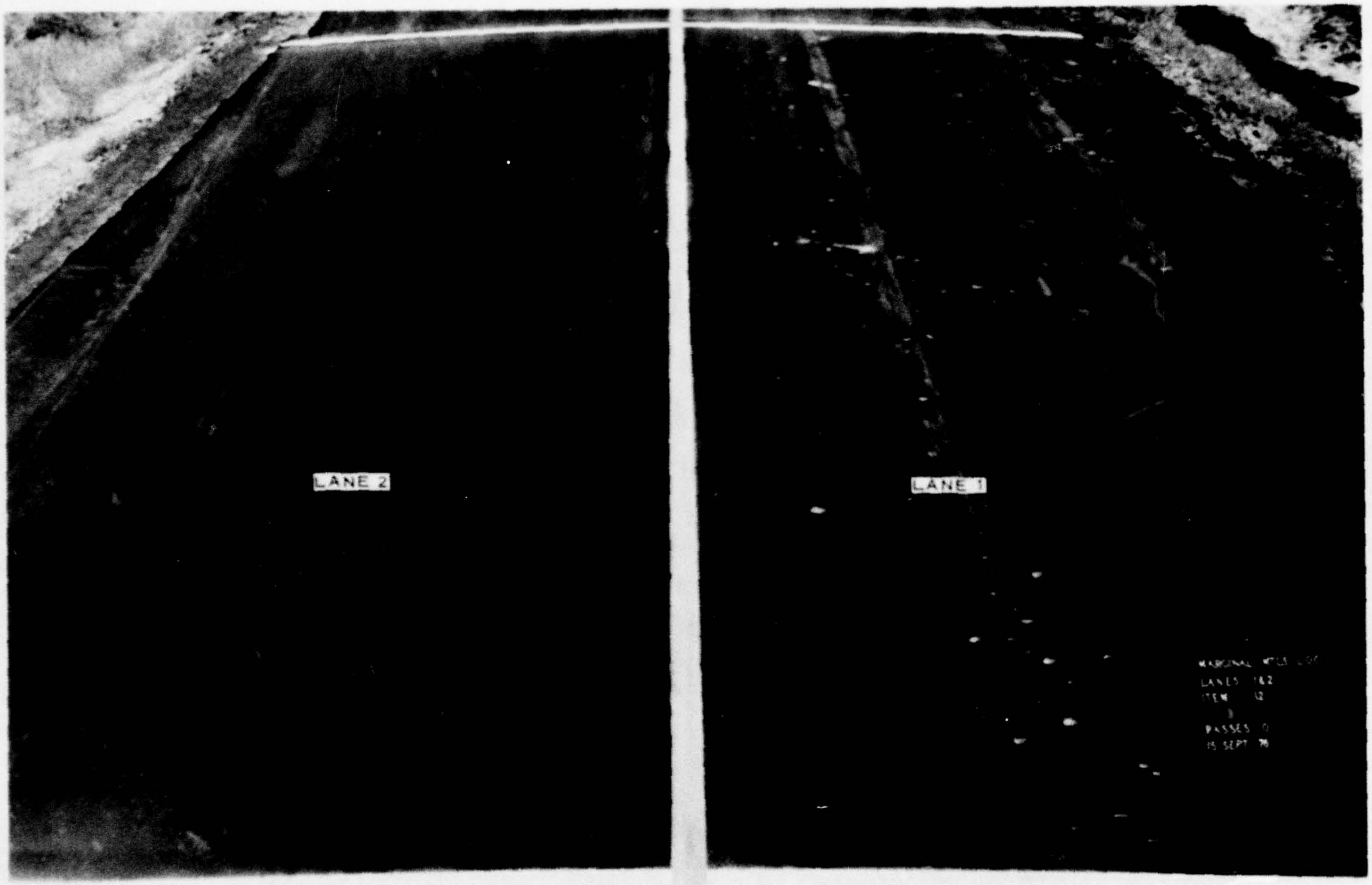


Photo 48. General view of item 12 prior to traffic


Photo 49. General view of item 11 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)


Photo 50. General view of item 12 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

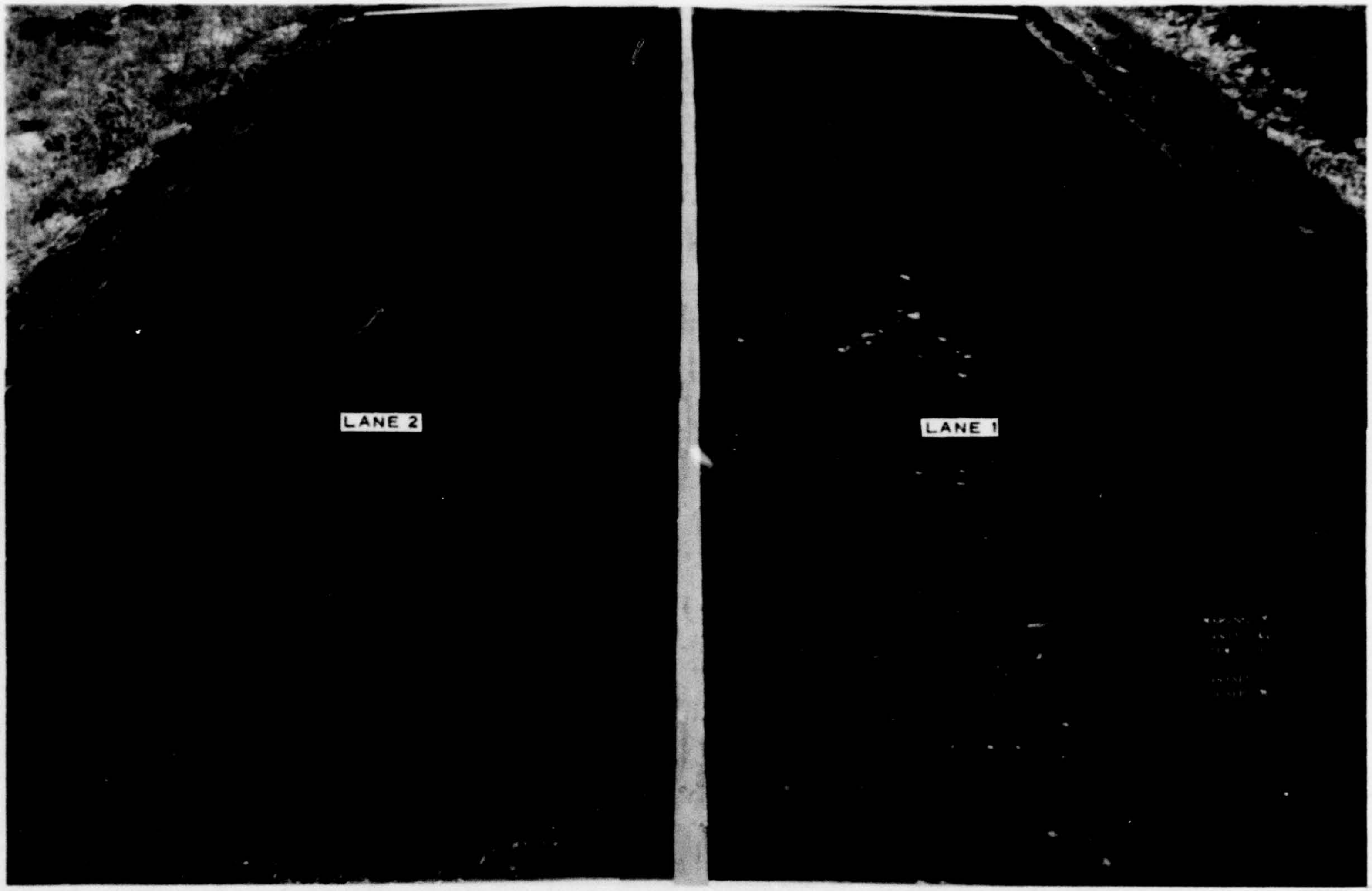


Photo 51. General view of item 13 prior to traffic

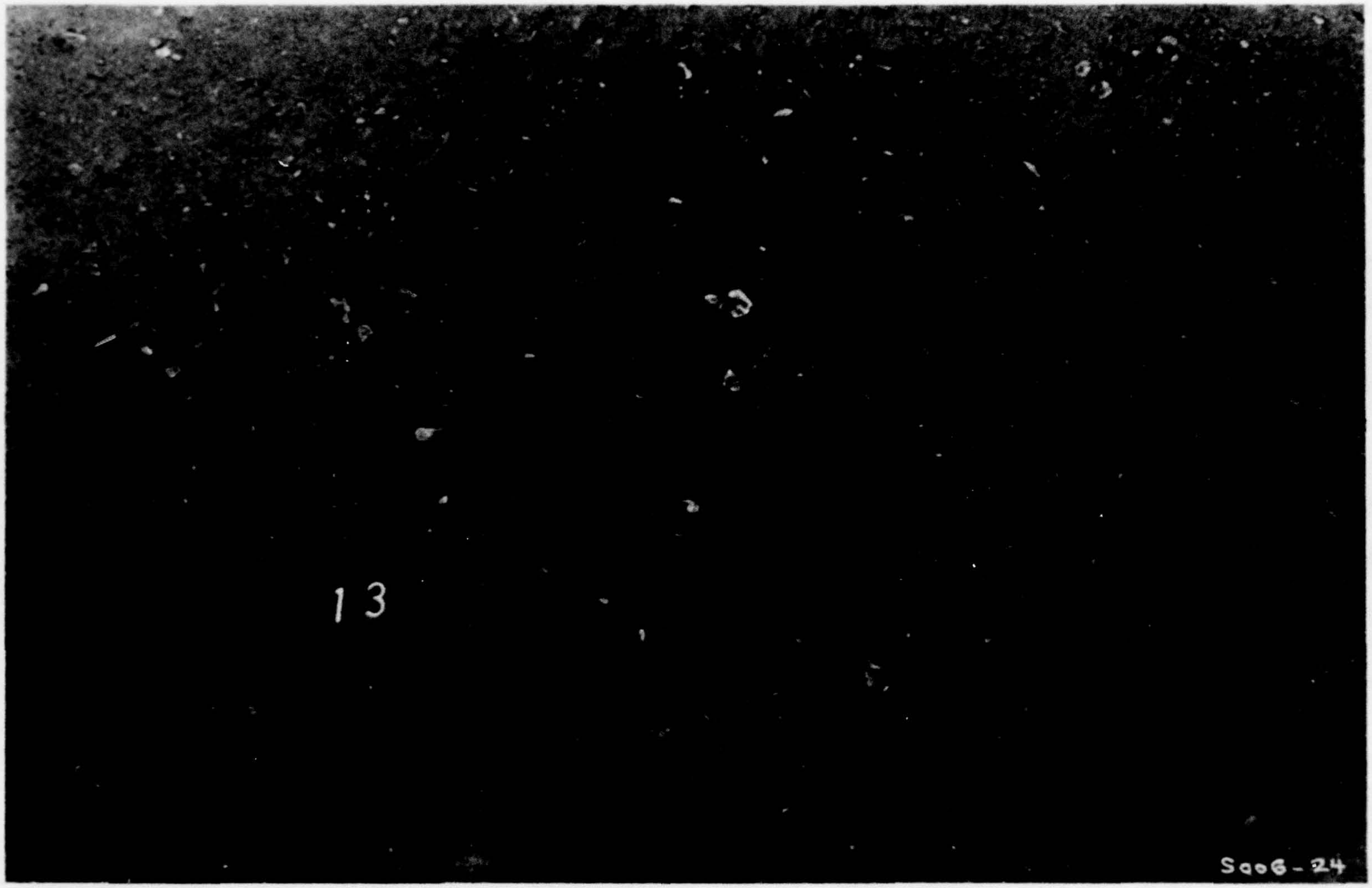


Photo 52. Surface raveling in item 13 after 1450 operations

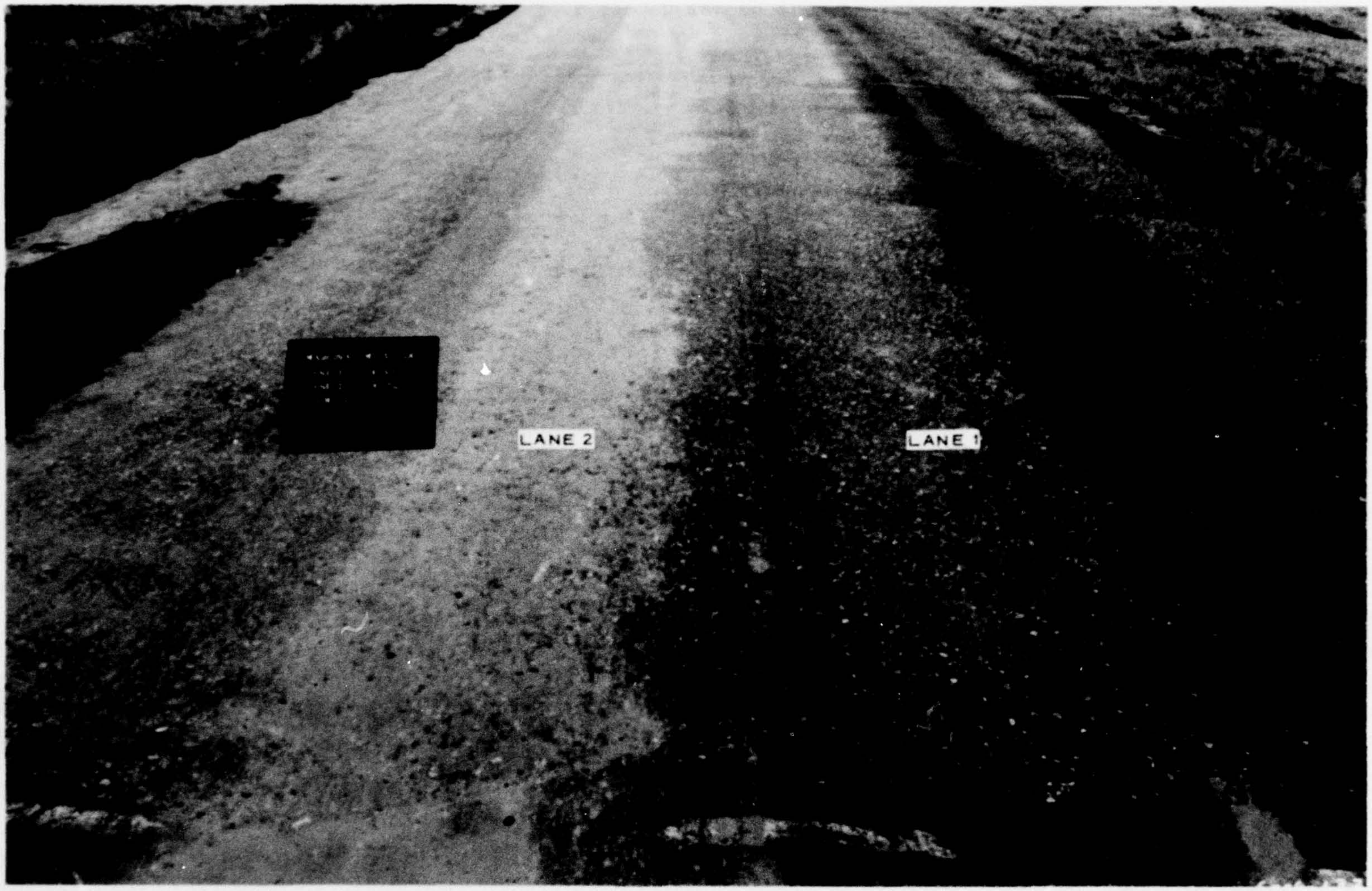


Photo 53. General view of item 13 after traffic (lane 1, 34,143 operations; lane 2, 106,752 operations)

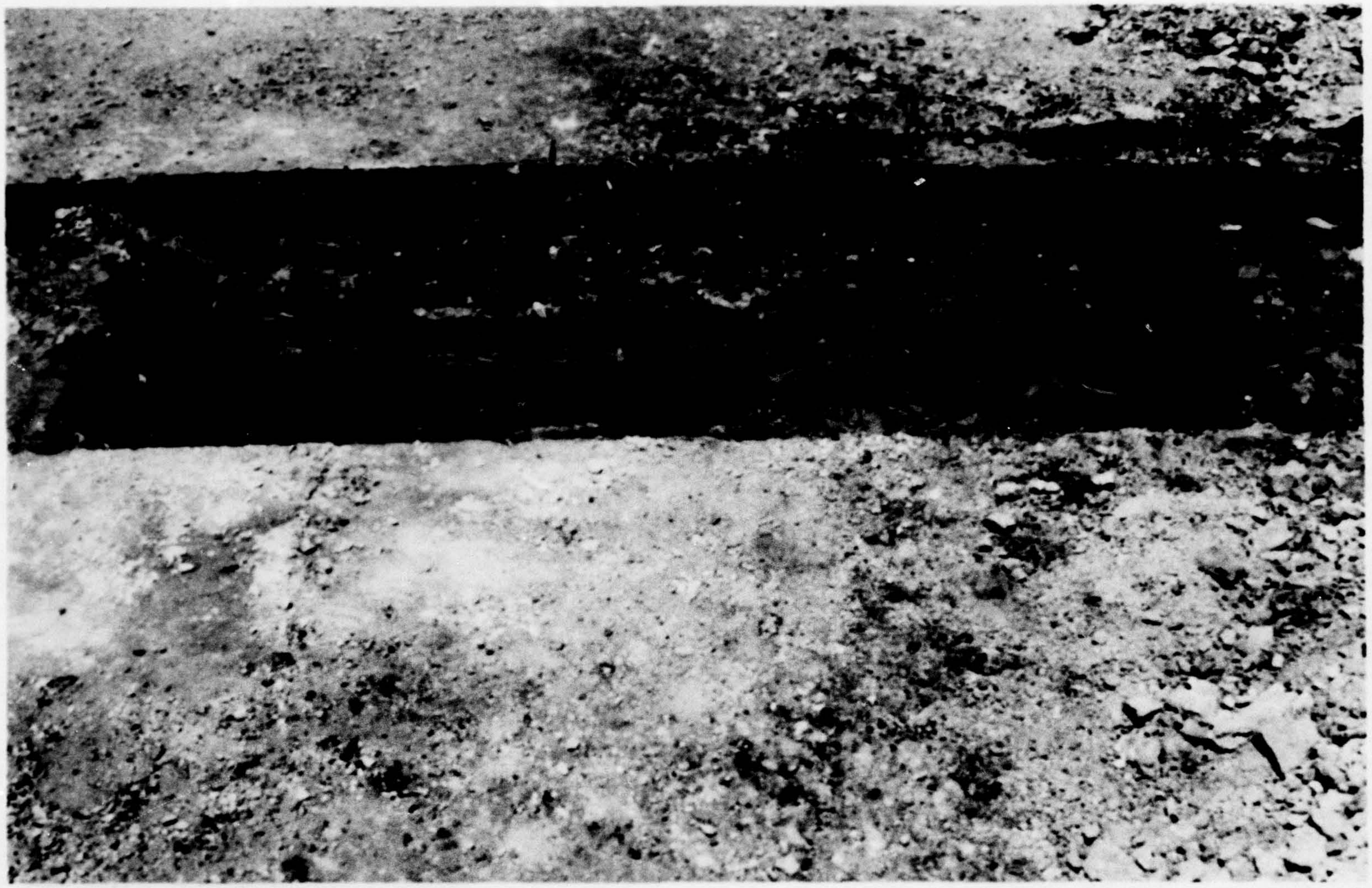

Photo 54. Test trench across item 5, lane 1

Photo 55. Test trench across item 6, lane 1

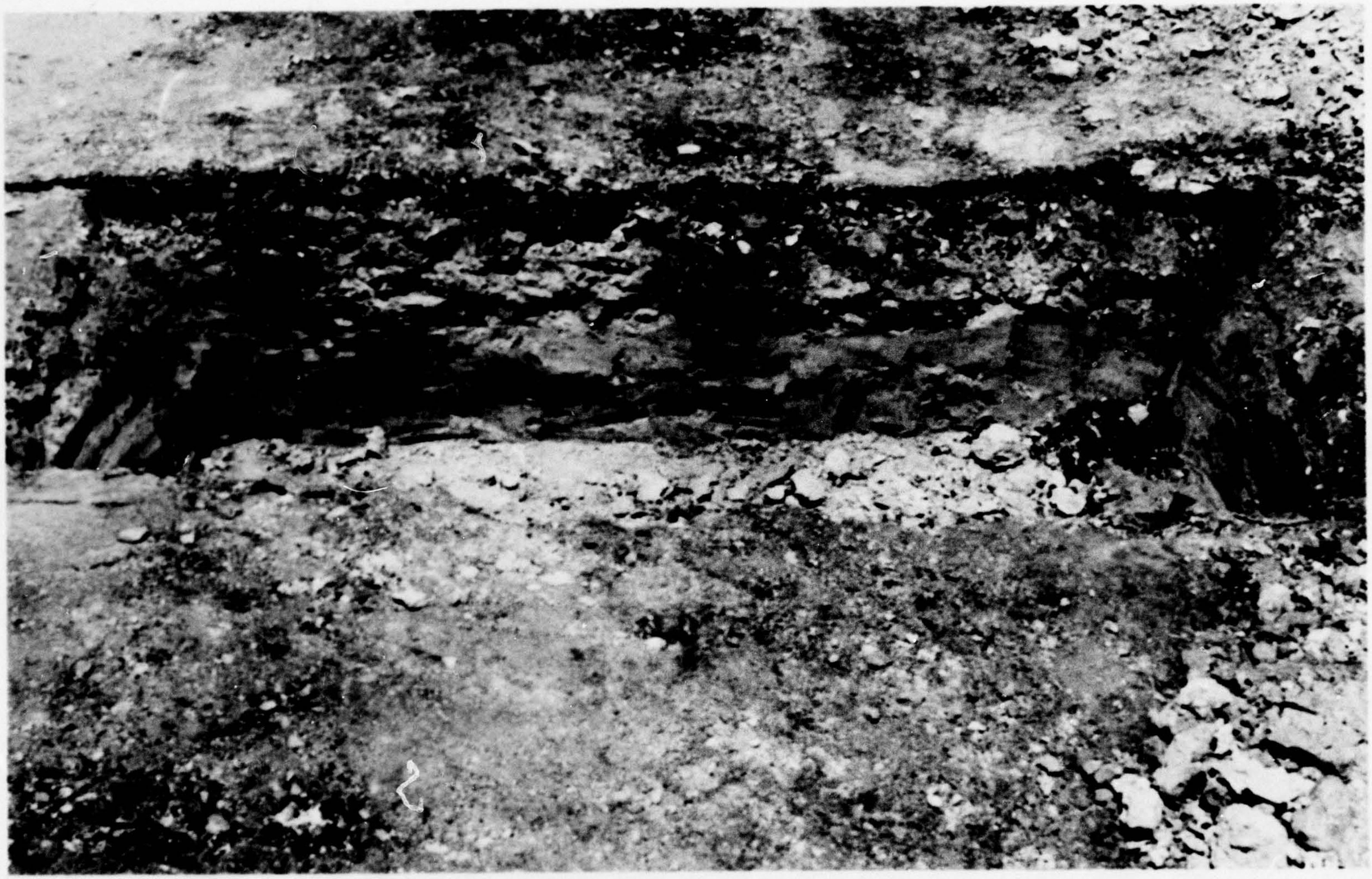

Photo 56. Test trench across item 7, lane 1

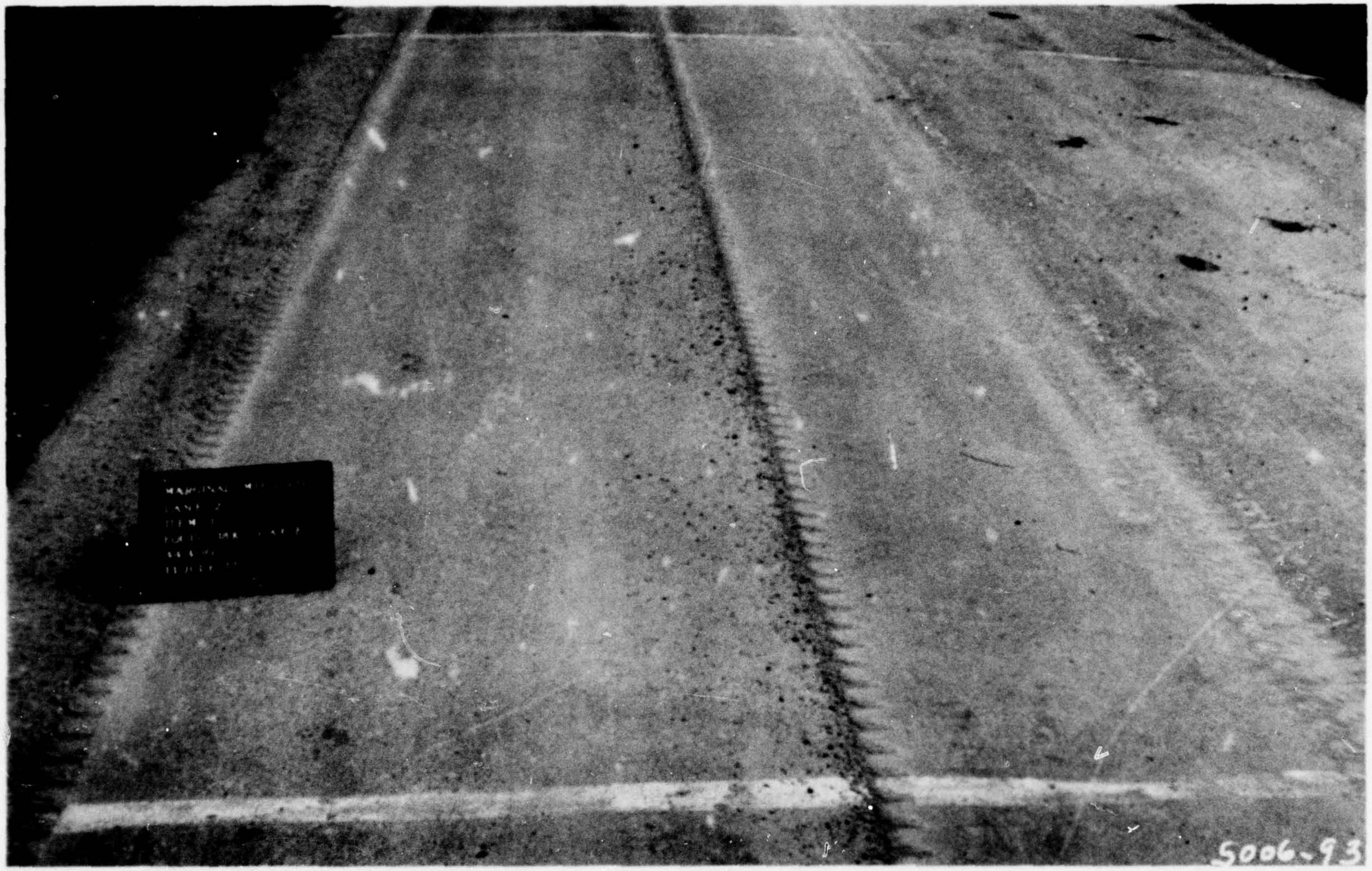


Photo 57. General view of item 1, lane 2, after 44,400 operations

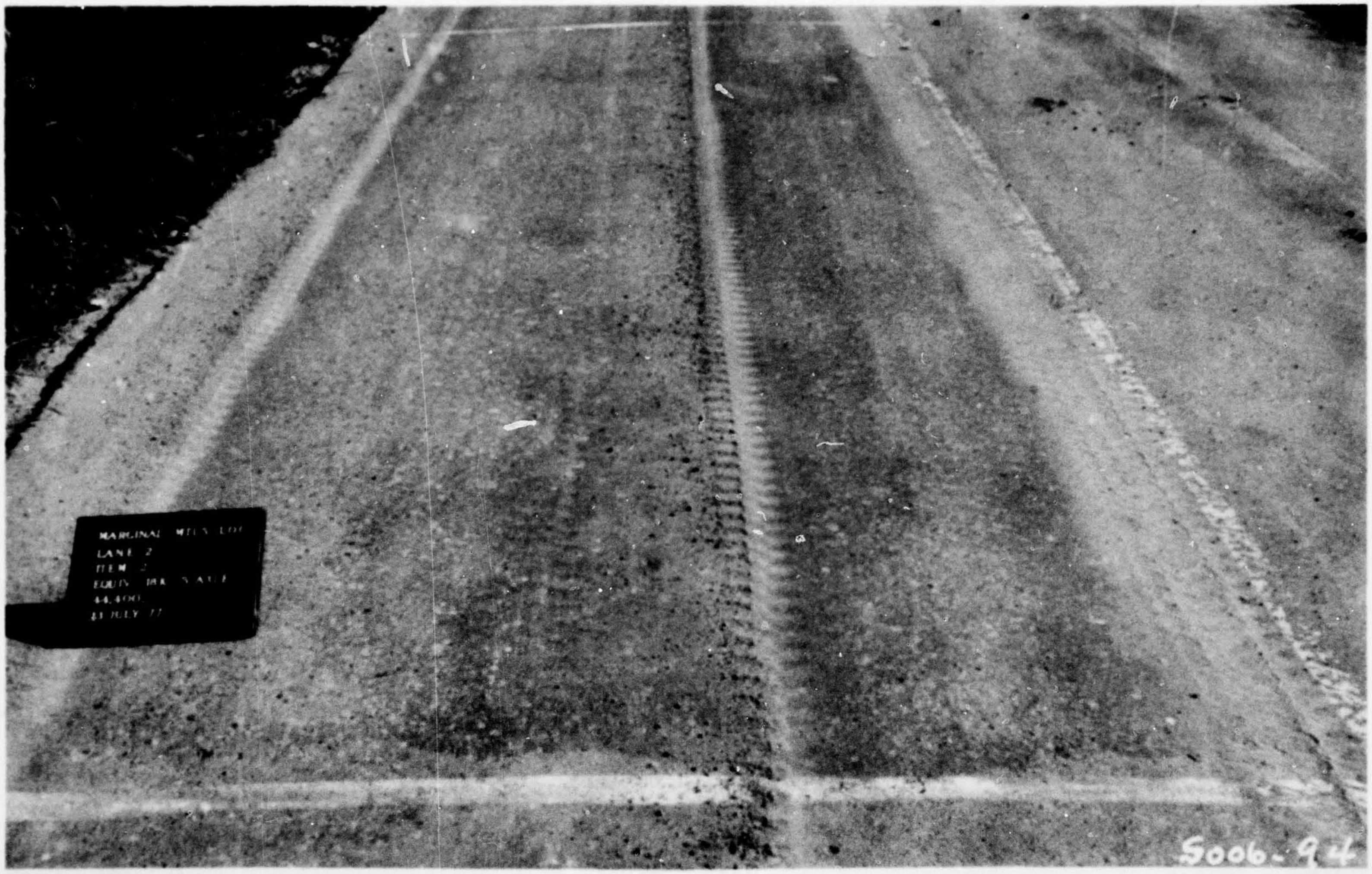


Photo 58. General view of item 2, lane 2, after 44,400 operations

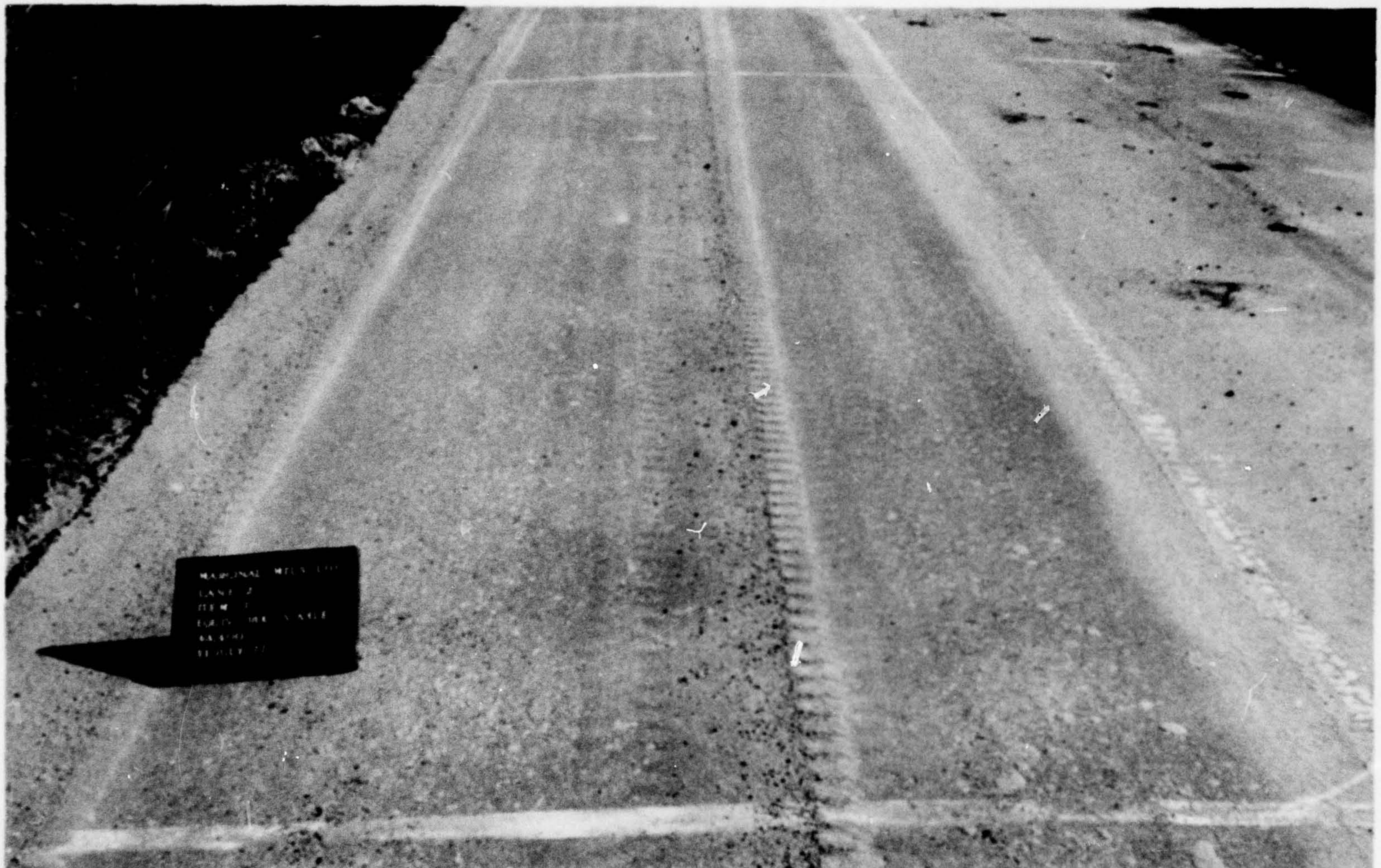

Photo 59. General view of item 3, lane 2, after 44,400 operations

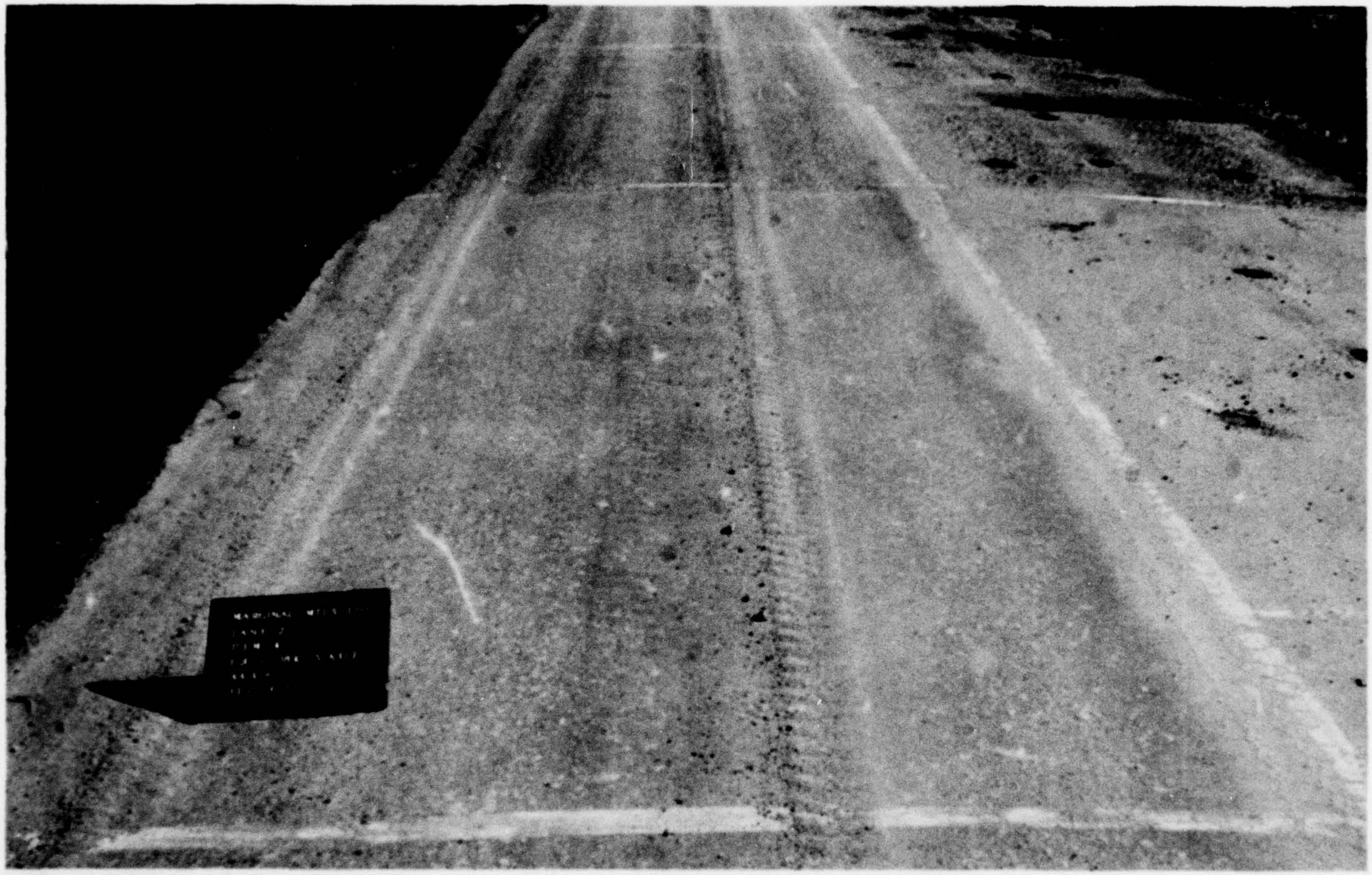

Photo 60. General view of item 4, lane 2, after 44,400 operations

Photo 61. Surface texture of item 7, lane 2, after 44,400 operations


Photo 62. General view of item 5, lane 2, after 44,400 operations

Photo 63. General view of item 6, lane 2, after 44,400 operations

Photo 64. General view of item 7, lane 2, after 44,400 operations

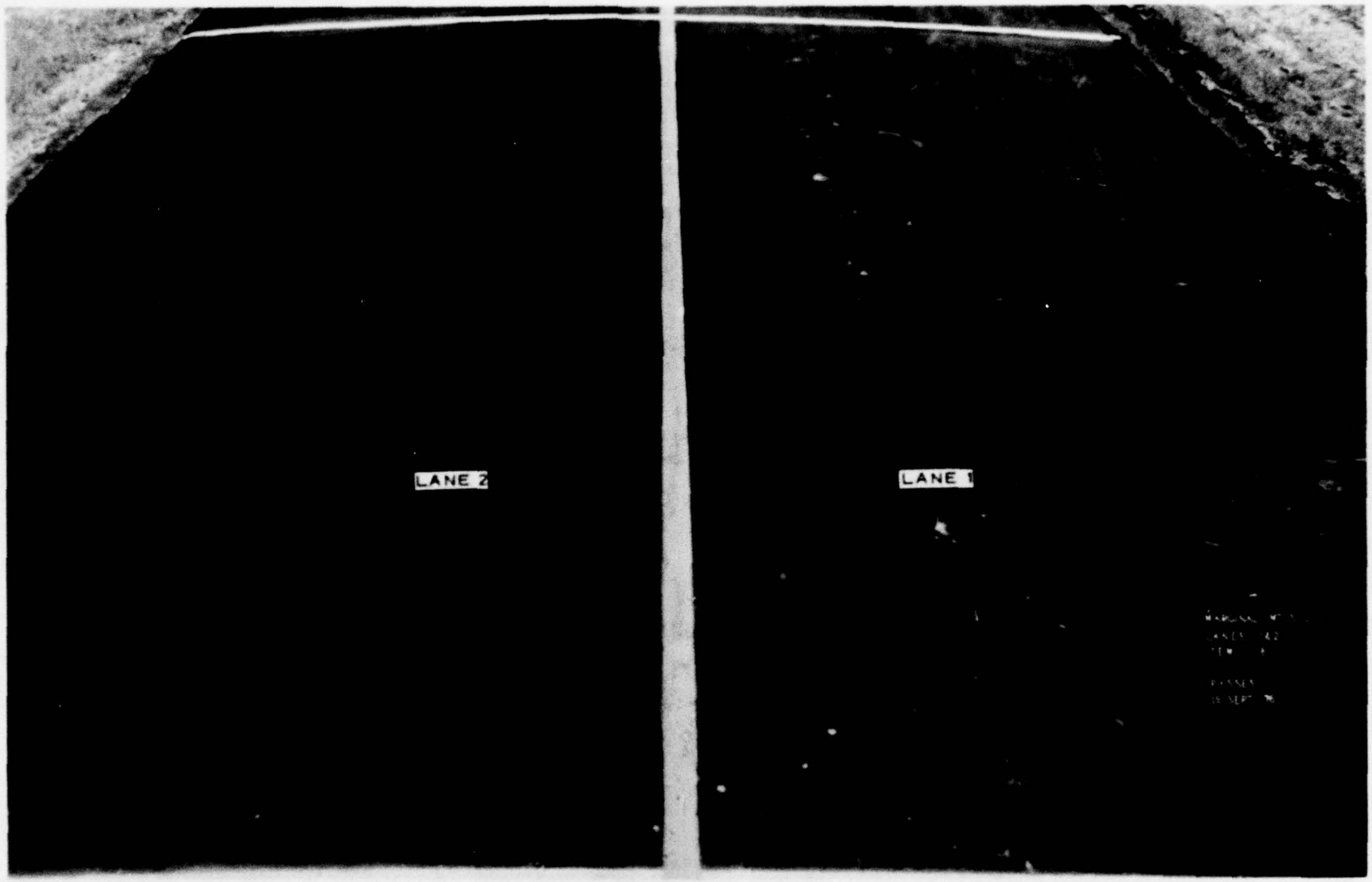


Photo 65. General view of item 8 prior to traffic

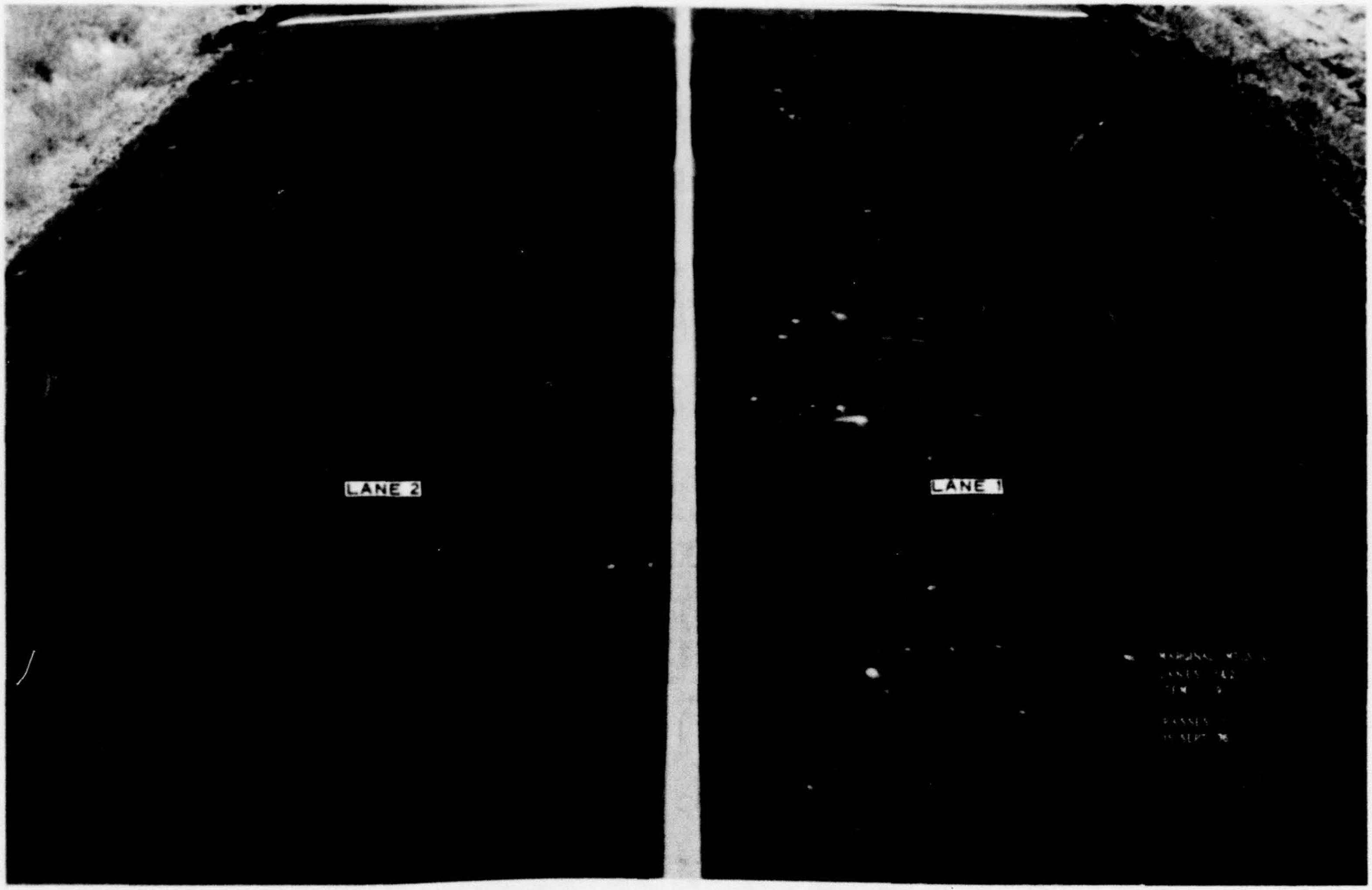


Photo 66. General view of item 9 prior to traffic

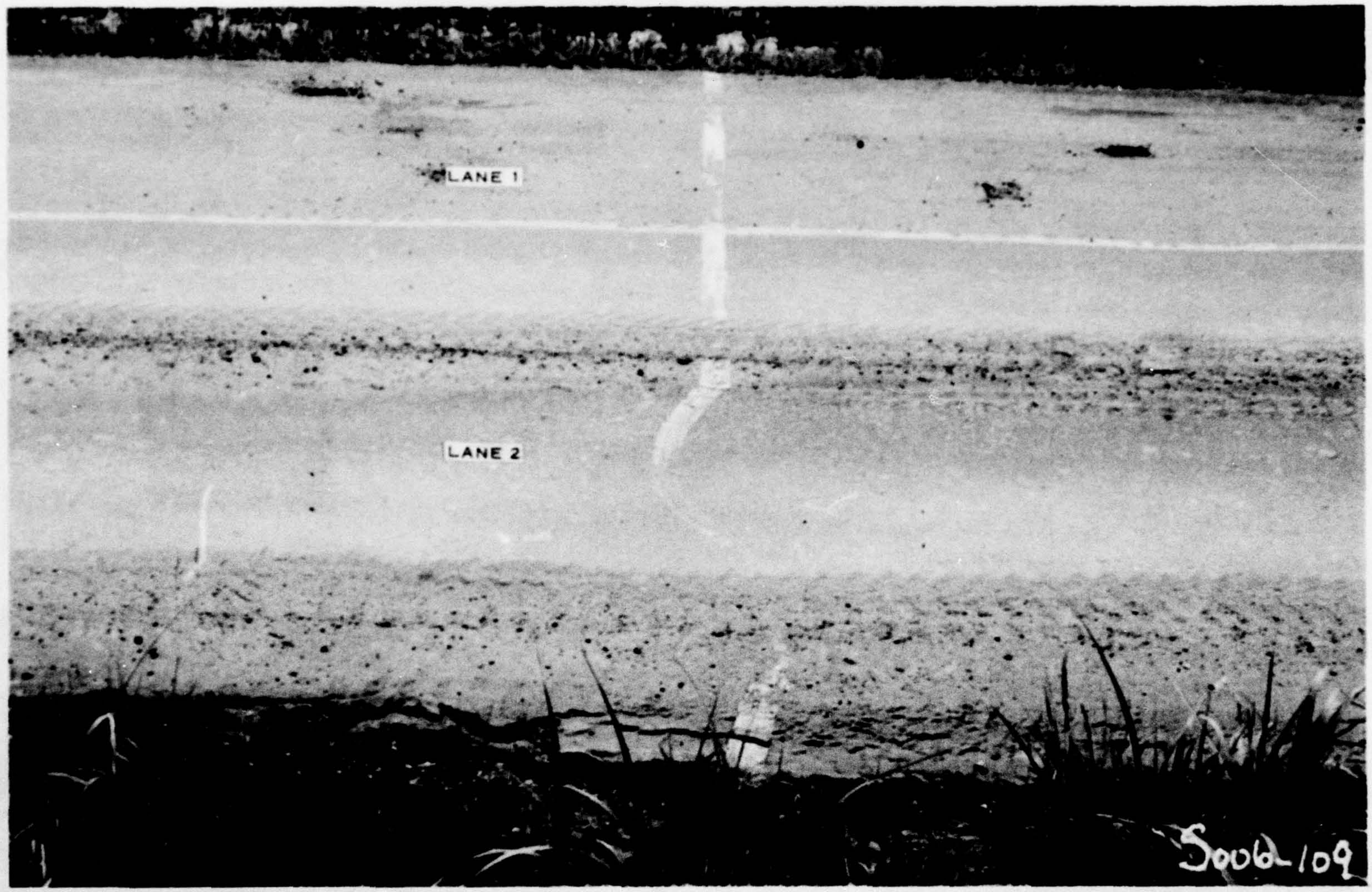


Photo 67. Comparison of shoving in item 10 after 34,143 operations in lane 1 and 44,400 operations in lane 2

Photo 68. General view of item 1, lane 1, after 125,000 operations

Photo 69. General view of item 2 (rigid pavement) prior to traffic

Photo 70. General view of item 2, lane 1, after 125,000 operations

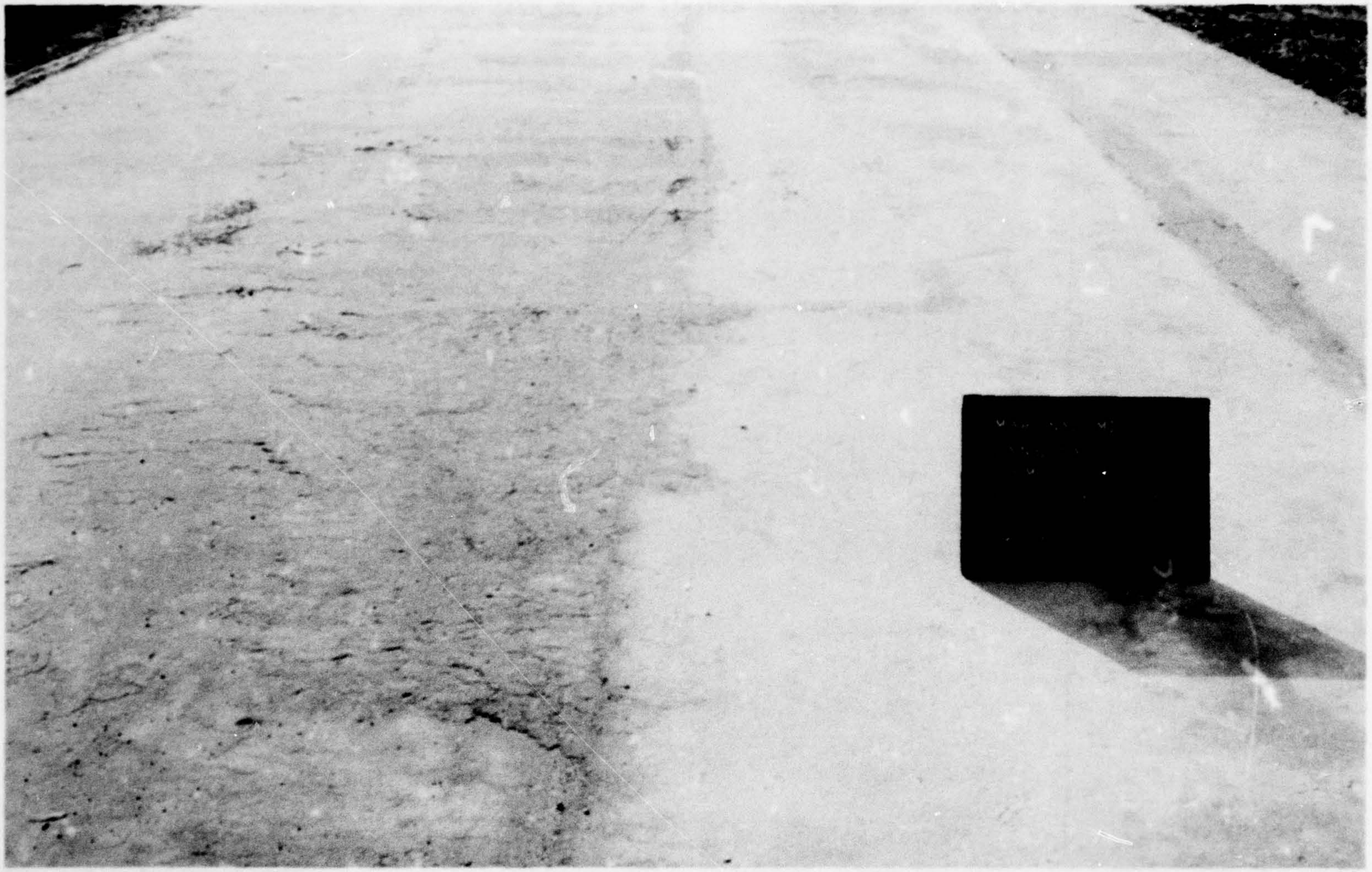

Photo 71. General view of item 3 (rigid pavement) prior to traffic

Photo 72. General view of item 3, lane 1, after 125,000 operations

Photo 73. General view of item 4 (rigid pavement) prior to traffic

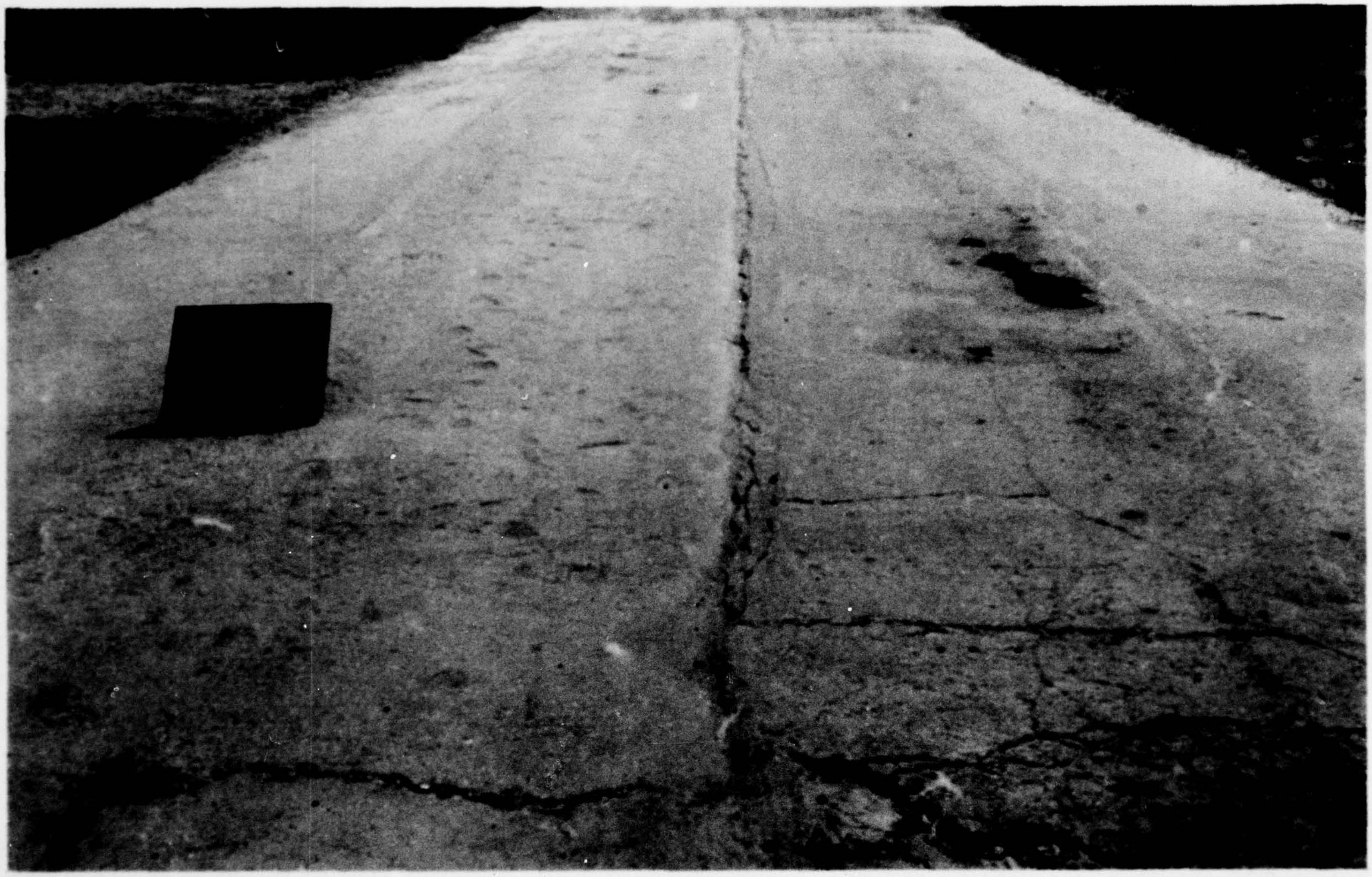

Photo 74. General view of item 4, lane 1, after 125,000 operations

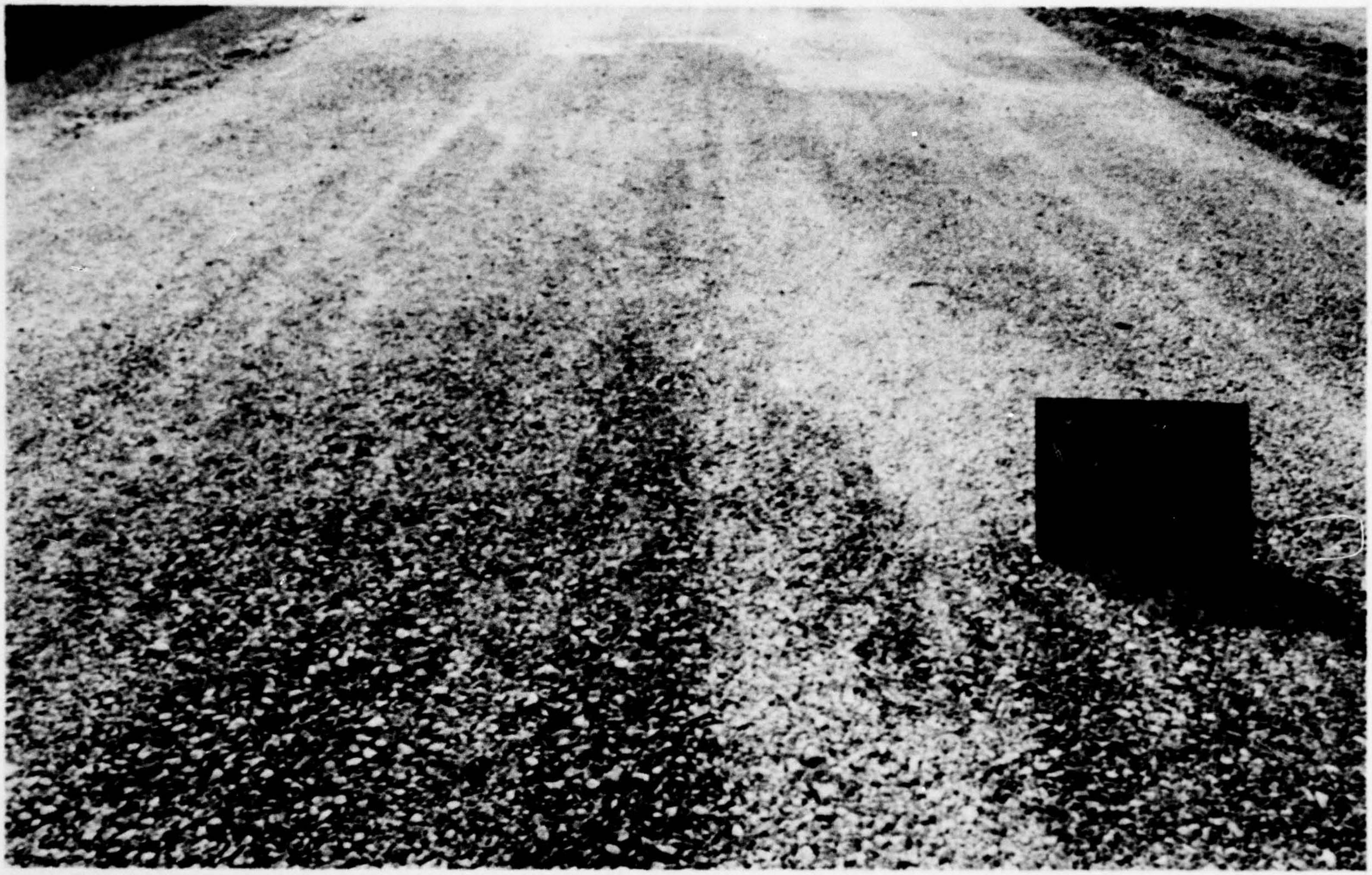

Photo 75. General view of item 5 (rigid pavement) prior to traffic

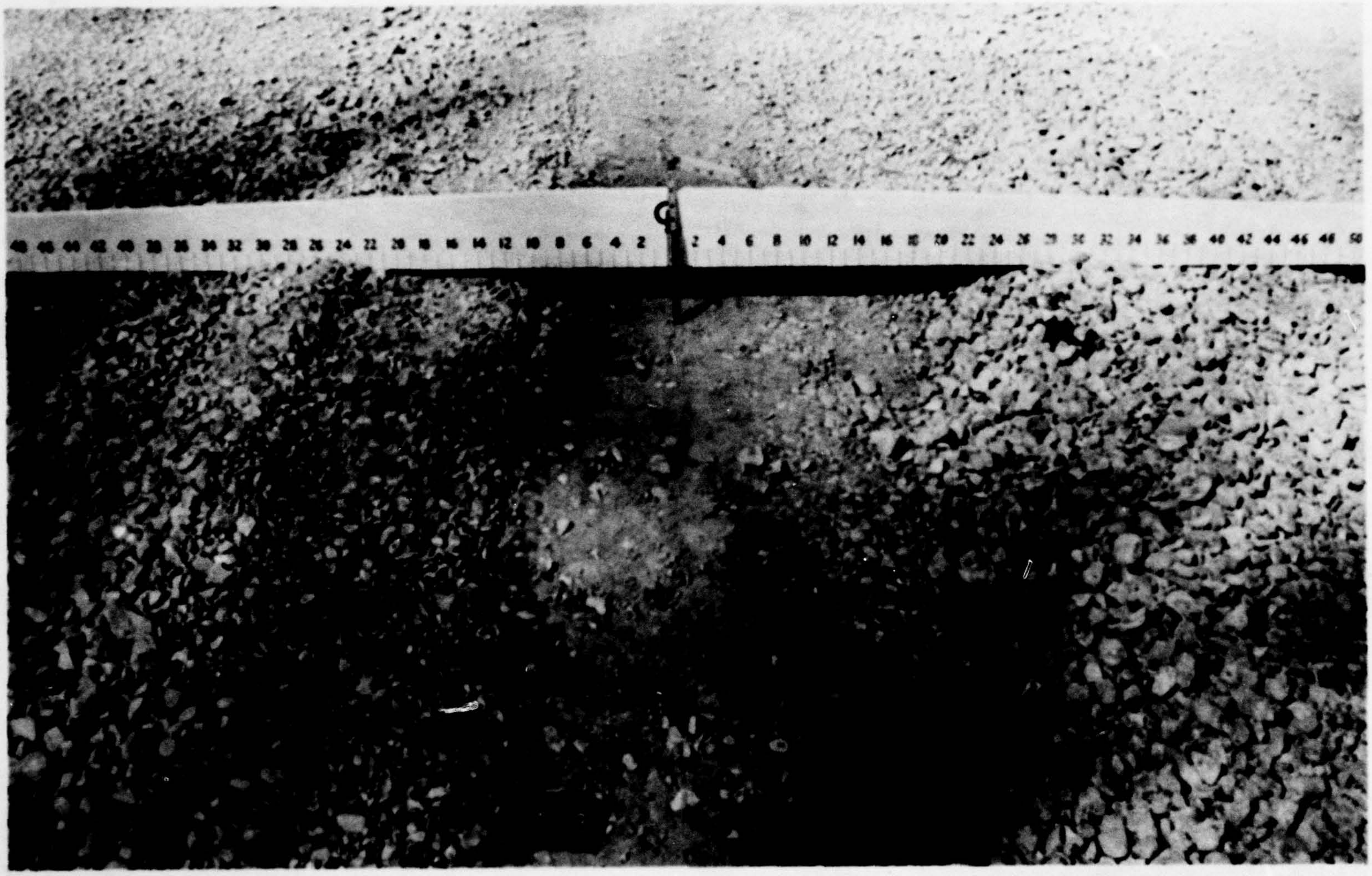

Photo 76. Close-up of 4-1/2-in.-deep rut in item 5 after 5390 operations

Photo 77. General view of item 5, lane 1, after 5390 operations (failure)

Photo 78. General view of item 6 (rigid pavement) prior to traffic

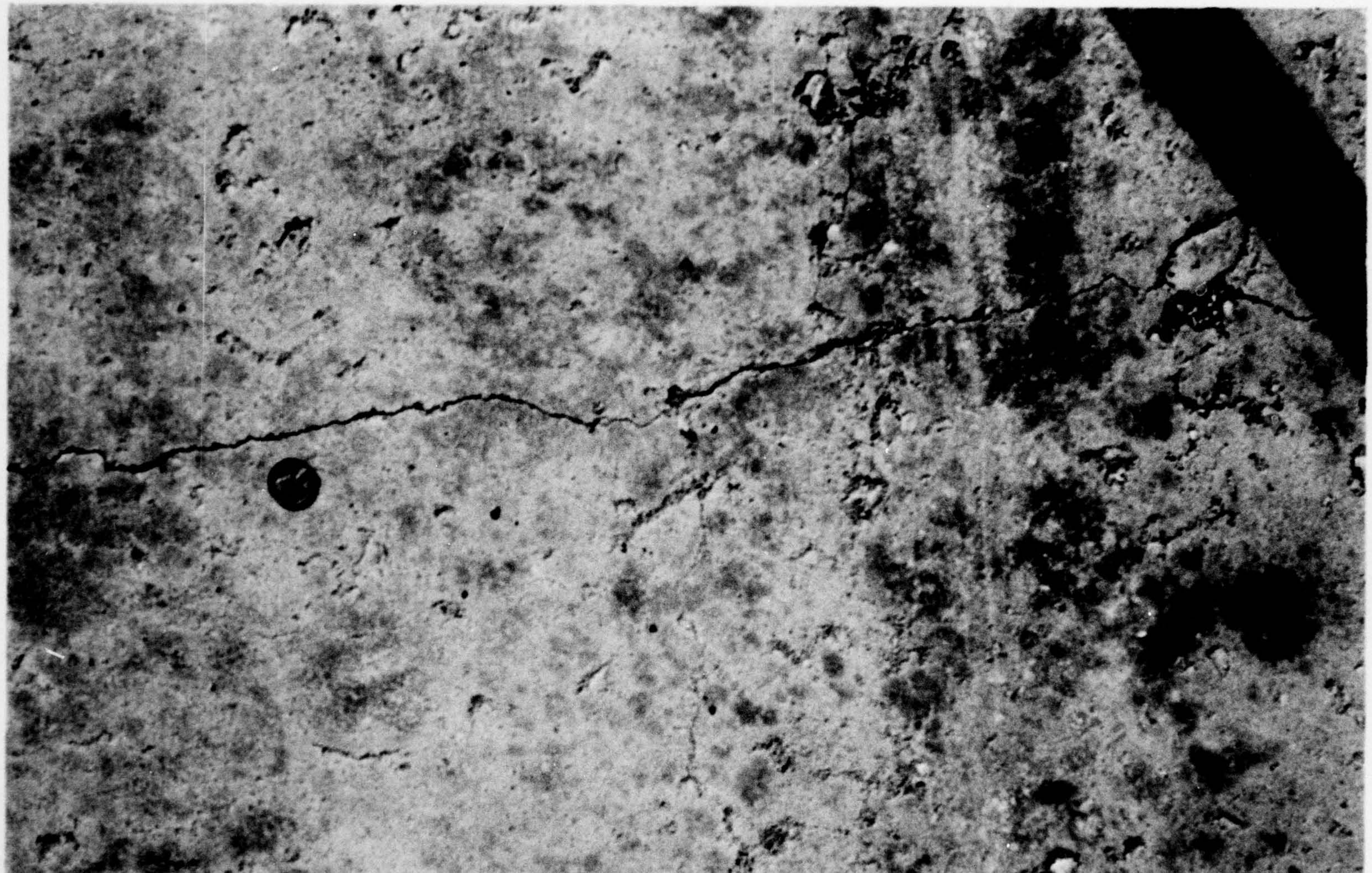

Photo 79. Contraction crack in item 6 prior to traffic

Photo 80. General view of item 6, lane 1, after 125,000 operations

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Grau, Robert Walter
Utilization of marginal construction materials for LOC / by Robert W. Grau. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
71, [98] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; GL-79-21)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Project No. 4A762719AT40, Task A2, Work Unit 017.
References: p. 71.

1. Aggregate tests. 2. Aggregates. 3. Bituminous concretes. 4. Construction materials. 5. Expedient surfacings. 6. Flexible pavements. 7. Lines of communication (LOC). 8. Rigid pavements. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; GL-79-21.
TA7.W34 no.GL-79-21